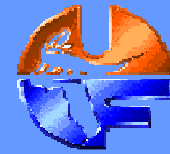




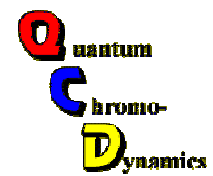
ISMD 2013



“softQCD” and Correlations

Conveners

Rick Field & Nick Van Remortel



Session 1 (9:00am-10:30am)

- ➔ Tevatron Energy Scan: Findings & Surprises (**Rick Field**).
- ➔ Results on the UE and DPS with the CMS Detector (**Roberta Arcidiacono**).
- ➔ Results on the UE and DPS with the ATLAS Detector (**Benjamin Wynne**).
- ➔ Underlying Event Studies at the Tevatron and the LHC (**Deepak Kar**).

Session 2 (11:00am-1:00pm)

- ➔ Aspects of soft QCD, correlations, particle spectra and multiplicities (**Nick Van Remortel**).
- ➔ Improved Isolation of the UE based on MB Trigger-Associated Hadron Correlations (**Tom Trainor**).
- ➔ Color Reconnection and Its Effect on Precise Measurements at the LHC (**Torbjörn Sjöstrand**).
- ➔ Studies of the Helix Model Using pp Collisions (**Sarka Todorova**).
- ➔ High Multiplicity in pp Interactions at U-70 (**Elena Kokoulina**).
- ➔ Measurement of Charged Kaon Correlations at Small Relative Momentum in the SELEX Experiment (**Grigory Nigmatkulov**).





ISMD13 “softQCD”



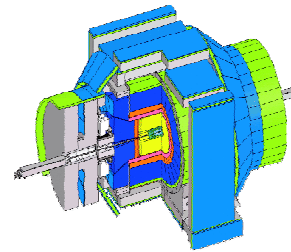
Tevatron Energy Scan: Findings & Surprises



Rick Field
University of Florida

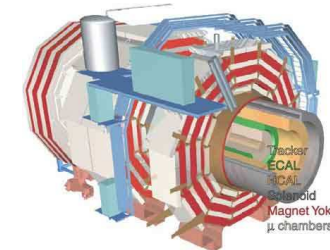
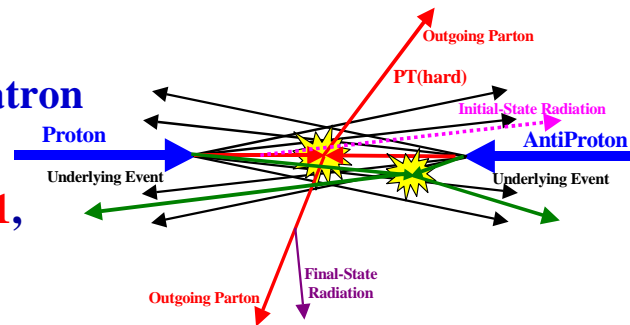
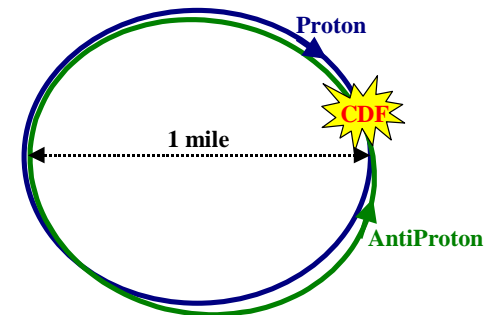
Outline of Talk

- ➔ LPCC MB&UE working group “common plots”.
- ➔ CDF MB “common plots” from the Tevatron Energy Scan.
- ➔ CDF UE “common plots” from the Tevatron Energy Scan.
- ➔ Mapping out the energy dependence of MB & UE: Tevatron to the LHC!
- ➔ CDF new UE observables from the Tevatron Energy Scan.
- ➔ Comparisons with PYTHIA 6.4 Tune Z1, PYTHIA 6.4 Tune Z2*, and PYTHIA 8 Tune 4C.
- ➔ Summary & Conclusions.



CDF Run 2

300 GeV, 900 GeV, 1.96 TeV



CMS at the LHC
900 GeV, 7 & 8 TeV

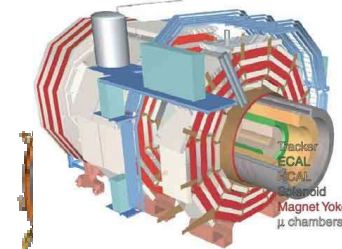
LPCC

MB&UE Working Group

LHC Physics Centre at CERN

MB & UE Common Plots

Quantum
Chromo-
Dynamics



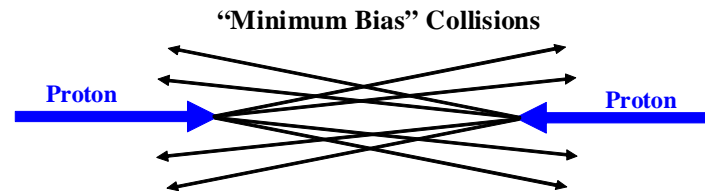
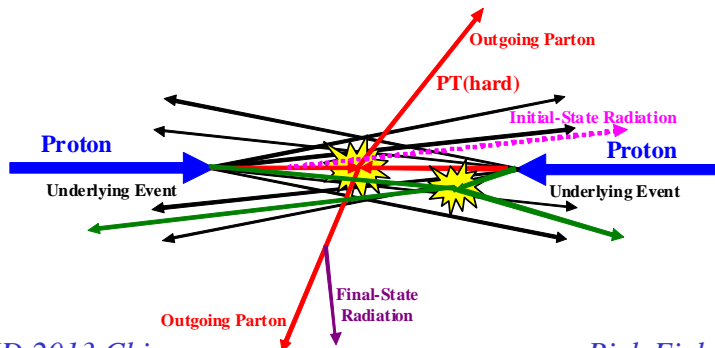
CMS

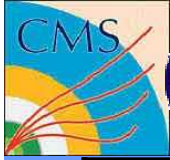


ATLAS

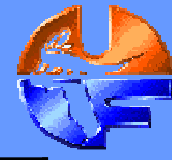


➔ The LPCC MB&UE Working Group has suggested several MB&UE “Common Plots” the all the LHC groups can produce and compare with each other.





CMS Common Plots

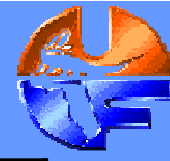


Observable	900 GeV	7 TeV
MB1: $dN_{\text{chg}}/d\eta N_{\text{chg}} \geq 1$ $\eta < 0.8 p_T > 0.5 \text{ GeV}/c \ \& \ 1.0 \text{ GeV}/c$	Done QCD-10-024	Done QCD-10-024
MB2: $dN_{\text{chg}}/dp_T N_{\text{chg}} \geq 1 \ \eta < 0.8$	Stalled	Stalled
MB3: Multiplicity Distribution $\eta < 0.8 p_T > 0.5 \text{ GeV}/c \ \& \ 1.0 \text{ GeV}/c$	Stalled	Stalled
MB4: $\langle p_T \rangle$ versus N_{chg} $\eta < 0.8 p_T > 0.5 \text{ GeV}/c \ \& \ 1.0 \text{ GeV}/c$	In progress (Antwerp)	In progress (Antwerp)
UE1: Transverse N_{chg} & PT_{sum} as defined by the leading charged particle, PT_{max} $\eta < 0.8 p_T > 0.5 \text{ GeV}/c \ \& \ 1.0 \text{ GeV}/c$	Done FSQ-12-020	Done FSQ-12-020

Direct charged particles (including leptons) corrected to the particle level with no corrections for SD or DD.



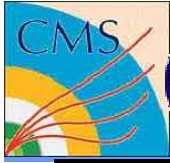
CMS Common Plots



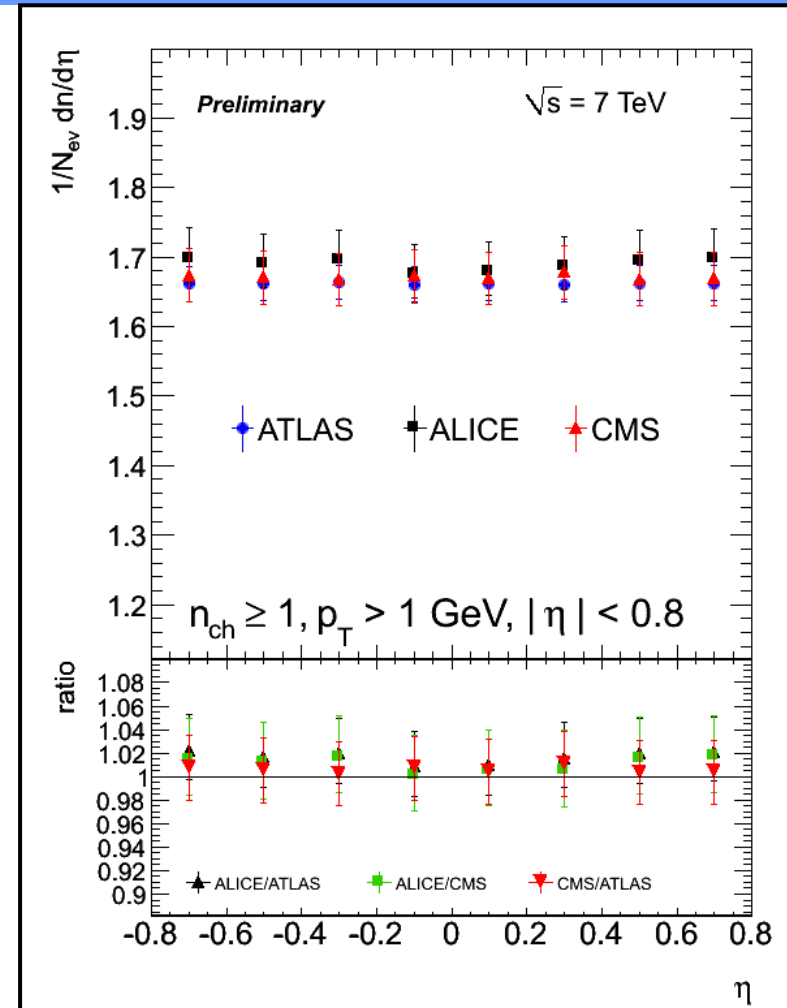
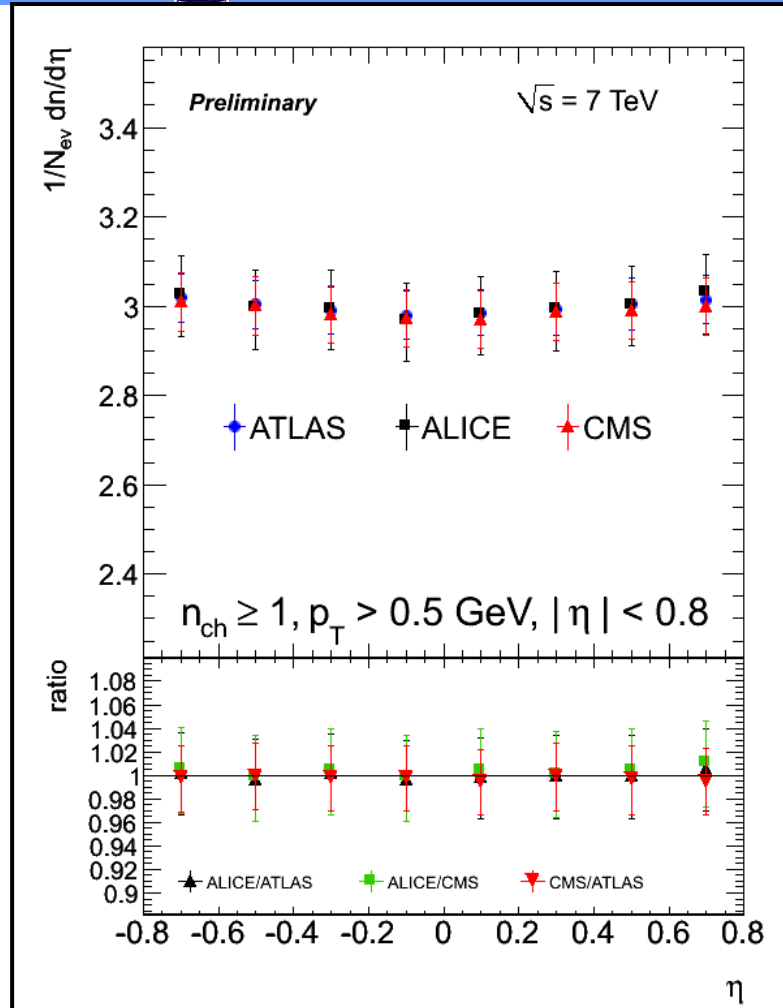
Observable	900 GeV	7 TeV
MB1: $dN_{\text{chg}}/d\eta$ ($N_{\text{chg}} \geq 1$) $ \eta < 0.8$ $p_T > 0.5 \text{ GeV}/c$ & $1.0 \text{ GeV}/c$	Done QC	Done QC 10-024
MB2: dN_{chg}/dp_T		Stalled
MB3: $\langle p_T \rangle$ $ \eta < 0.8$ $p_T > 0.5 \text{ GeV}/c$		Stalled
MB4: $\langle p_T \rangle$ vertex $ \eta < 0.8$ $p_T > 0.5 \text{ GeV}/c$		Stalled
UE1: $E_{\text{transverse}}/N_{\text{chg}}$ defined by the leading particle, PT_{max} $ \eta < 0.8$ $p_T > 0.5 \text{ GeV}/c$ & $1.0 \text{ GeV}/c$	Done FSC	Done FSC 12-020

Note that all the “common plots” require at least one charged particle with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$! This done so that the plots are less sensitive to SD and DD.

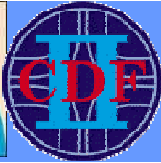
Direct charged particles (including leptons) corrected to the particle level with no corrections for SD or DD.



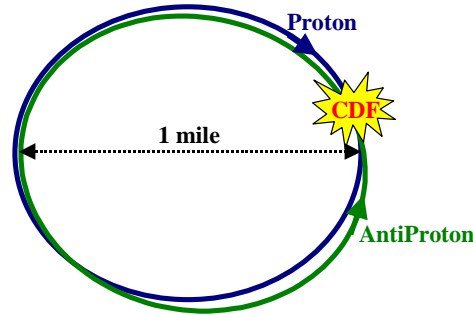
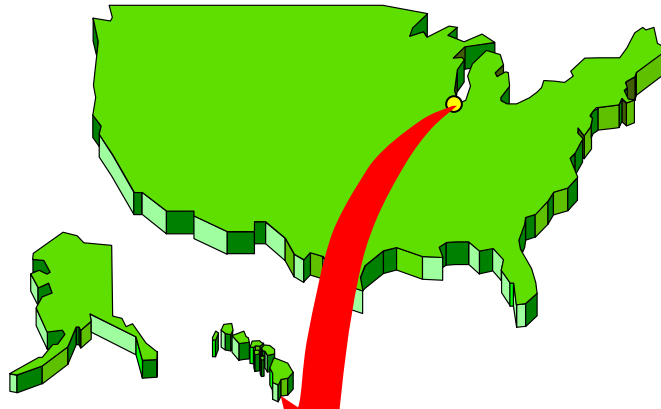
MB Common Plots 7 TeV



Direct charged particles (including leptons) corrected to the particle level with no corrections for SD or DD.



Tevatron Energy Scan



➔ Just before the shutdown of the Tevatron CDF has collected more than 10M “min-bias” events at several center-of-mass energies!

300 GeV 12.1M MB Events

900 GeV 54.3M MB Events



CDF Common Plots



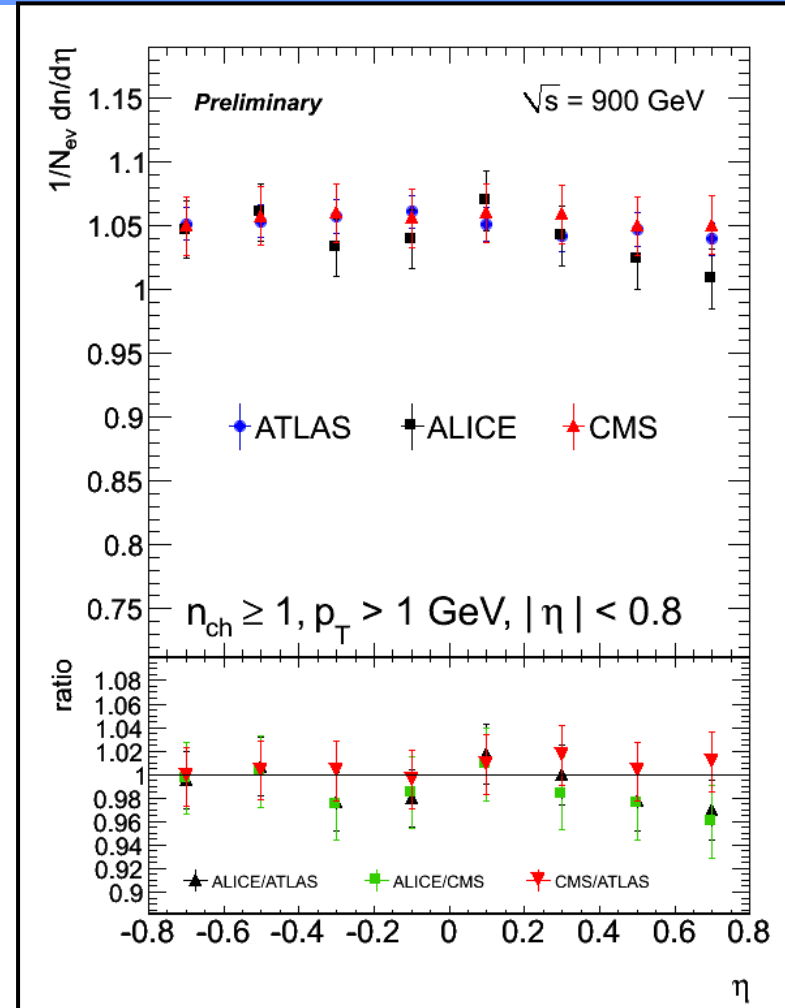
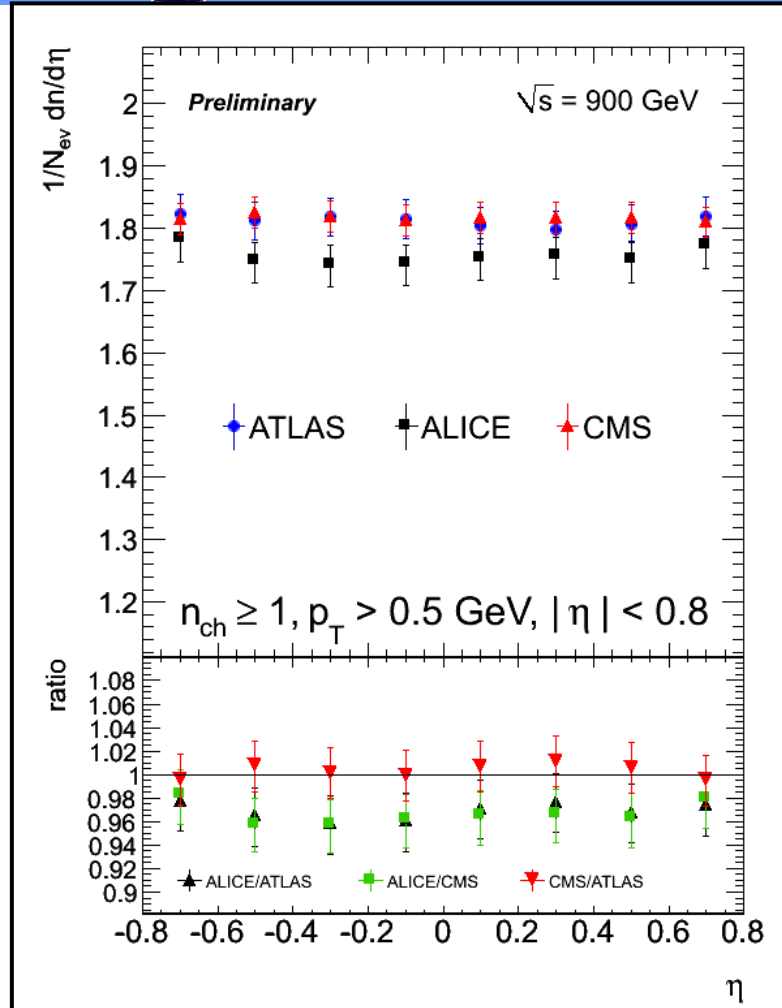
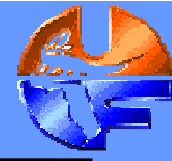
Observable	300 GeV	900 GeV	1.96 TeV
MB1: $dN_{\text{chg}}/d\eta N_{\text{chg}} \geq 1$ $\eta < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	Done	Done	Done
MB2: $dN_{\text{chg}}/dp_T N_{\text{chg}} \geq 1$ $\eta < 0.8$	In progress	In progress	In progress
MB3: Multiplicity Distribution $\eta < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	In progress	In progress	In progress
MB4: $\langle p_T \rangle$ versus Nchg $\eta < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	In progress	In progress	In progress
UE1: Transverse Nchg & PTsum as defined by the leading charged particle, PTmax $\eta < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	$p_T > 0.5$ GeV/c Done	$p_T > 0.5$ GeV/c Done	$p_T > 0.5$ GeV/c Done

Direct charged particles (including leptons) corrected to the particle level with no corrections for SD or DD.

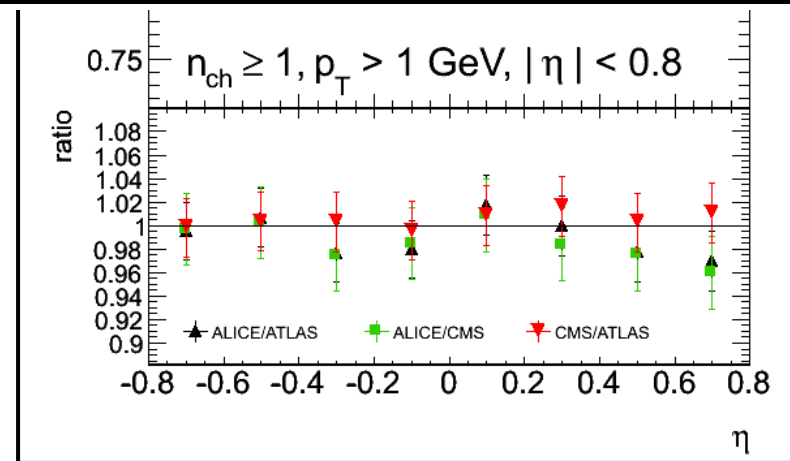
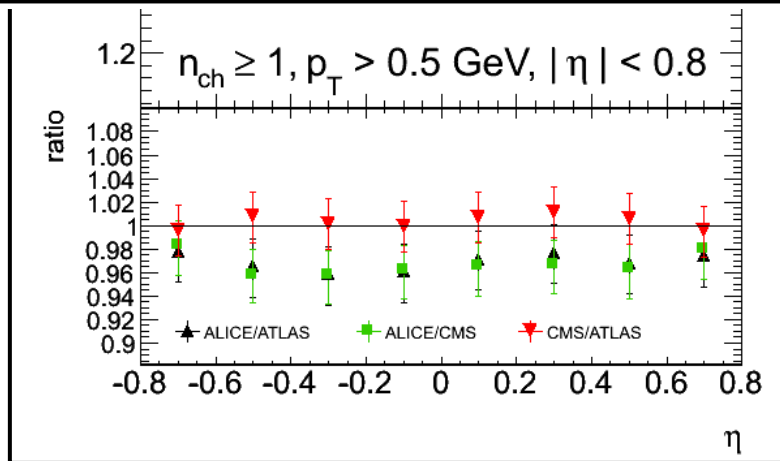
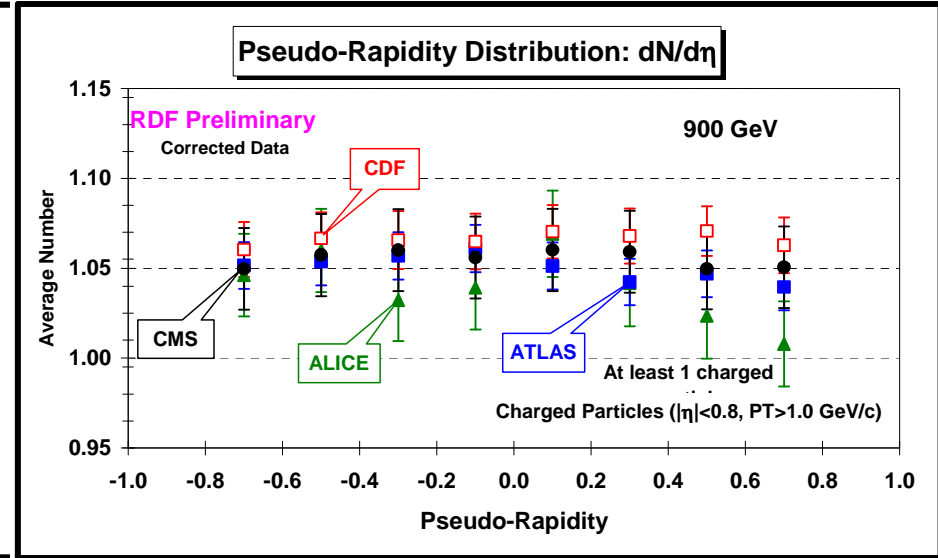
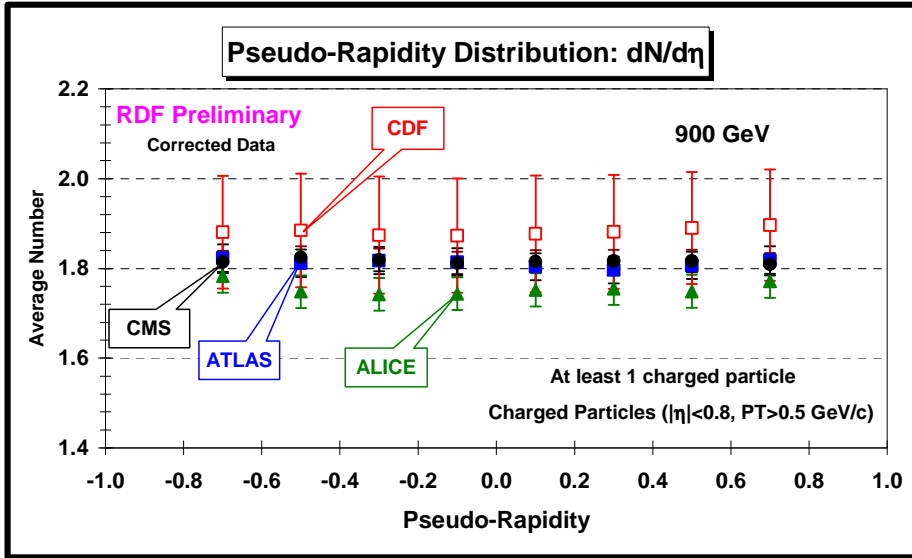
R. Field, C. Group, and D. Wilson.



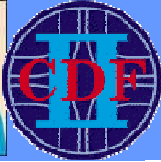
MB Common Plots 900 GeV



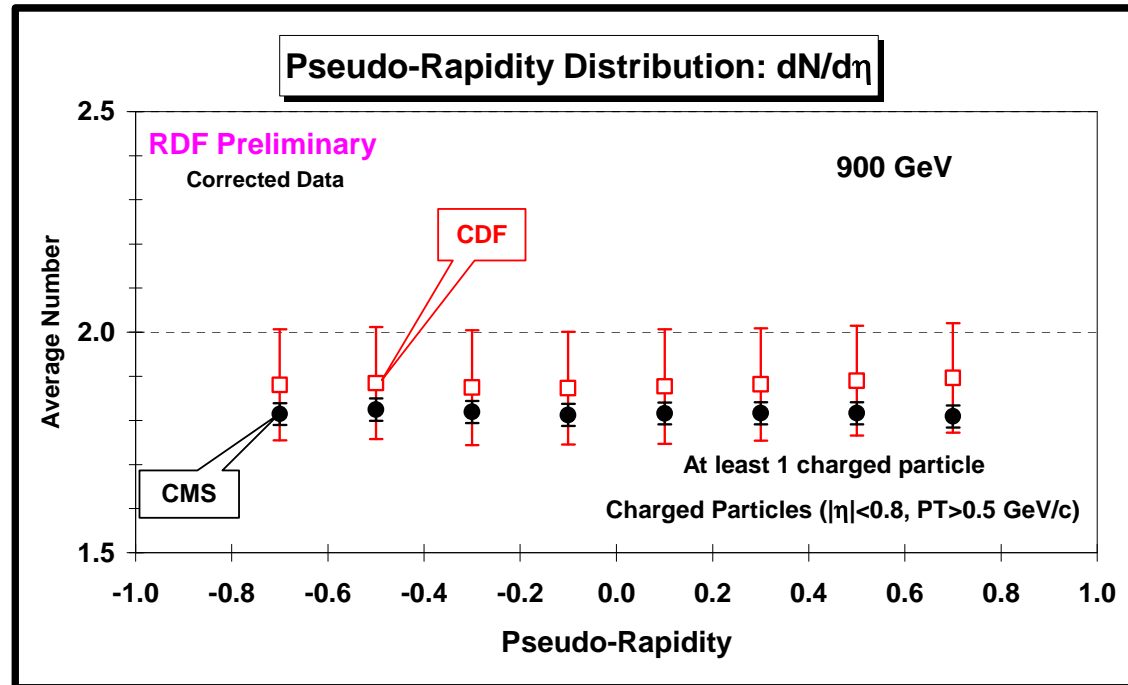
Direct charged particles (including leptons) corrected to the particle level with no corrections for SD or DD.



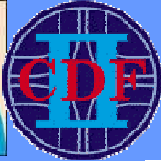
Direct charged particles (including leptons) corrected to the particle level with no corrections for SD or DD.



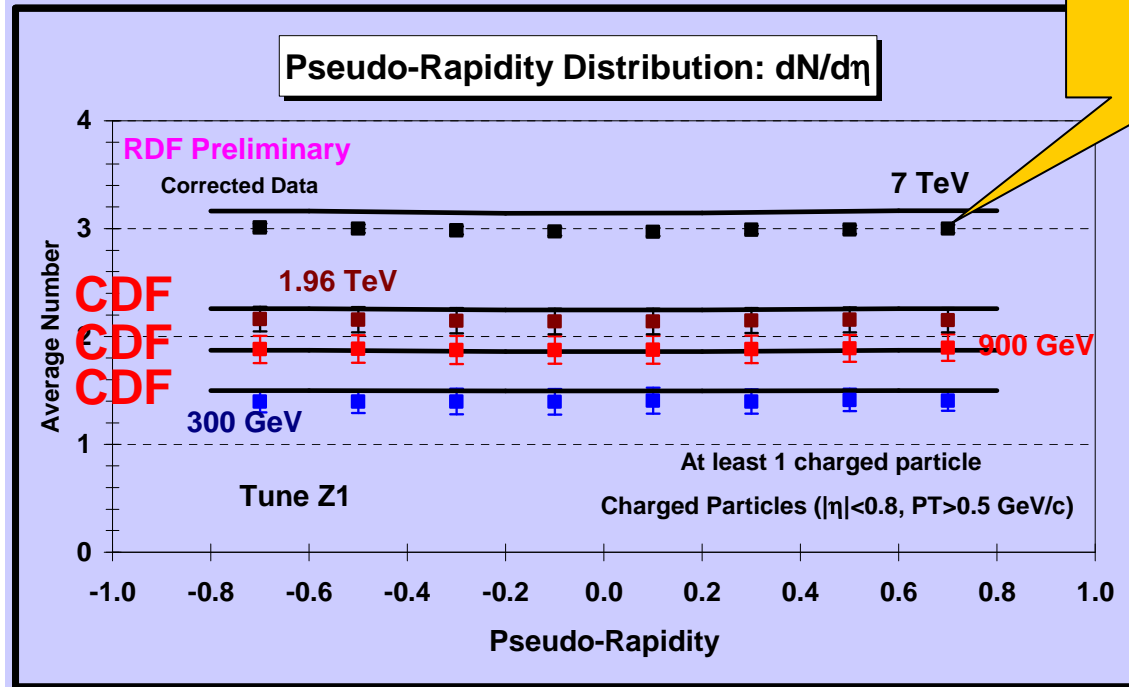
New CDF MB Data



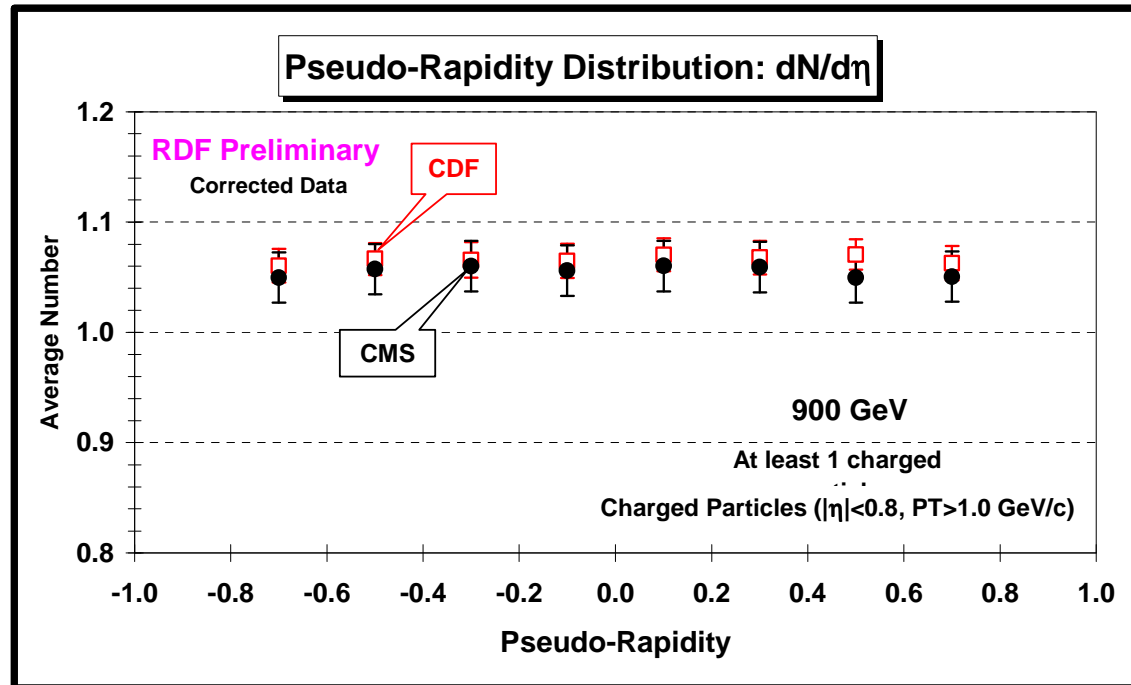
- ➔ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV on on pseudo-rapidity distribution of charged particles, $dN/d\eta$, with $p_T > 0.5$ GeV/c. Events are required to have at least one charged particle with $|\eta| < 0.8$ and $p_T > 0.5$ GeV/c. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**



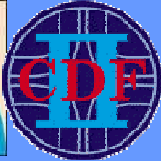
New CDF MB Data



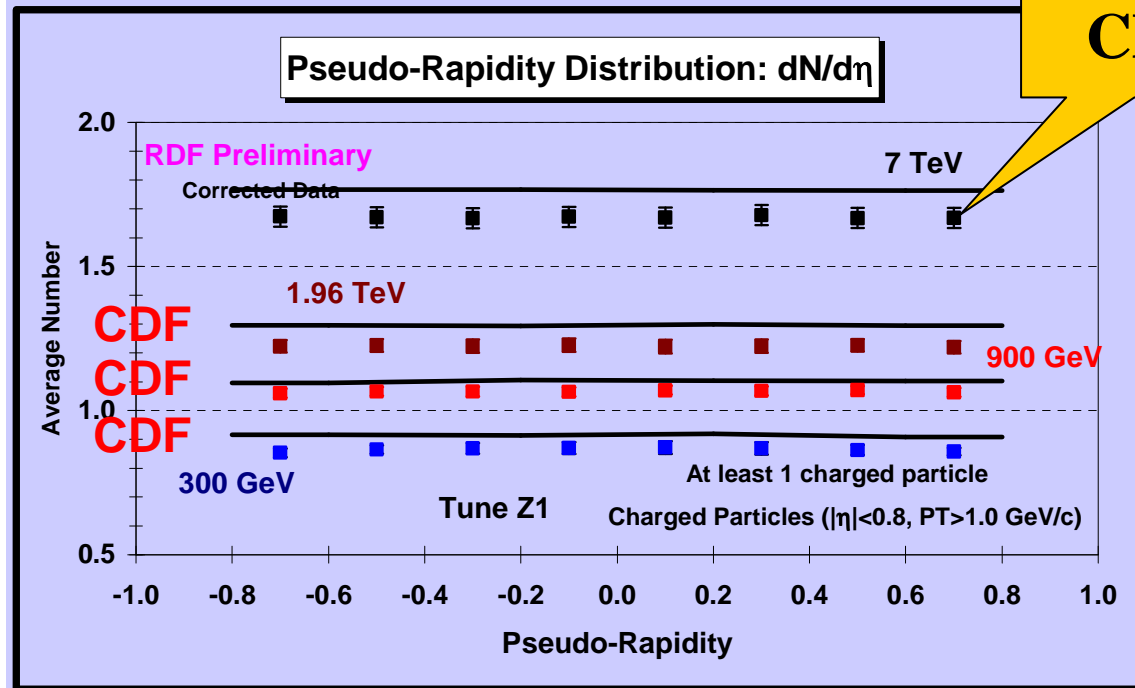
- ➔ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV on on pseudo-rapidity distribution of charged particles, $dN/d\eta$, with $p_T > 0.5 \text{ GeV}/c$. Events are required to have at least one charged particle with $|\eta| < 0.8$ and $p_T > 0.5 \text{ GeV}/c$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**



- ➔ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV** on on pseudo-rapidity distribution of charged particles, $dN/d\eta$, with $p_T > 1.0$ GeV/c. Events are required to have at least one charged particle with $|\eta| < 0.8$ and $p_T > 1.0$ GeV/c. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.



New CDF MB Data

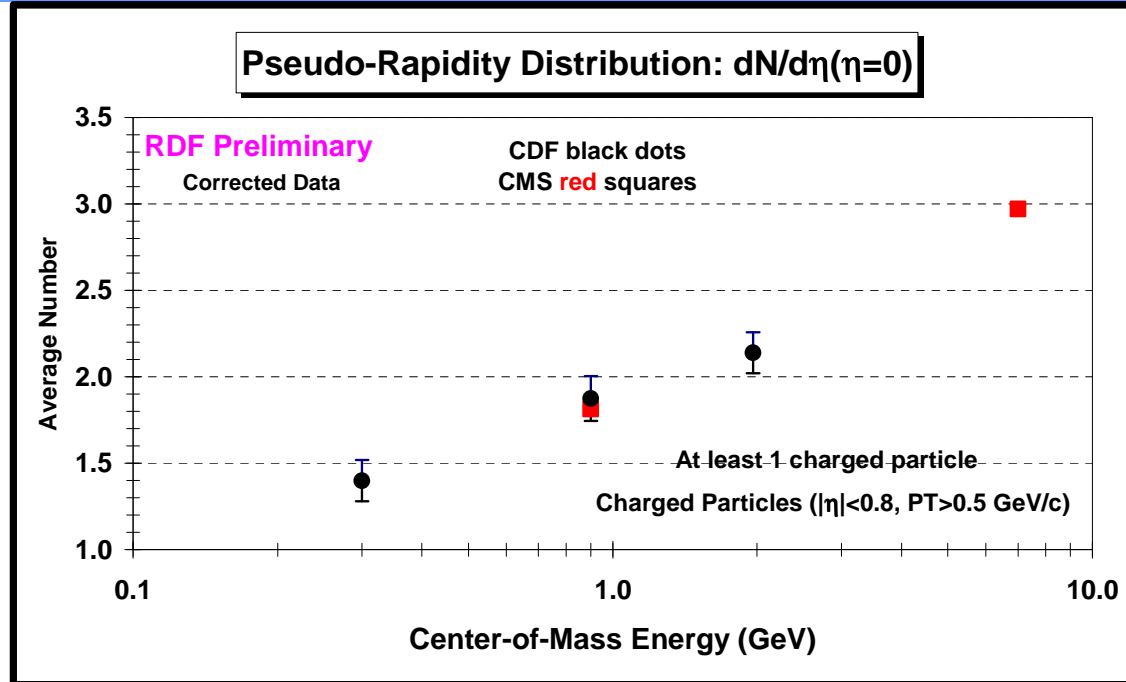


CMS

- ➔ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV on on pseudo-rapidity distribution of charged particles, $dN/d\eta$, with $p_T > 1.0 \text{ GeV}/c$. Events are required to have at least one charged particle with $|\eta| < 0.8$ and $p_T > 1.0 \text{ GeV}/c$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**



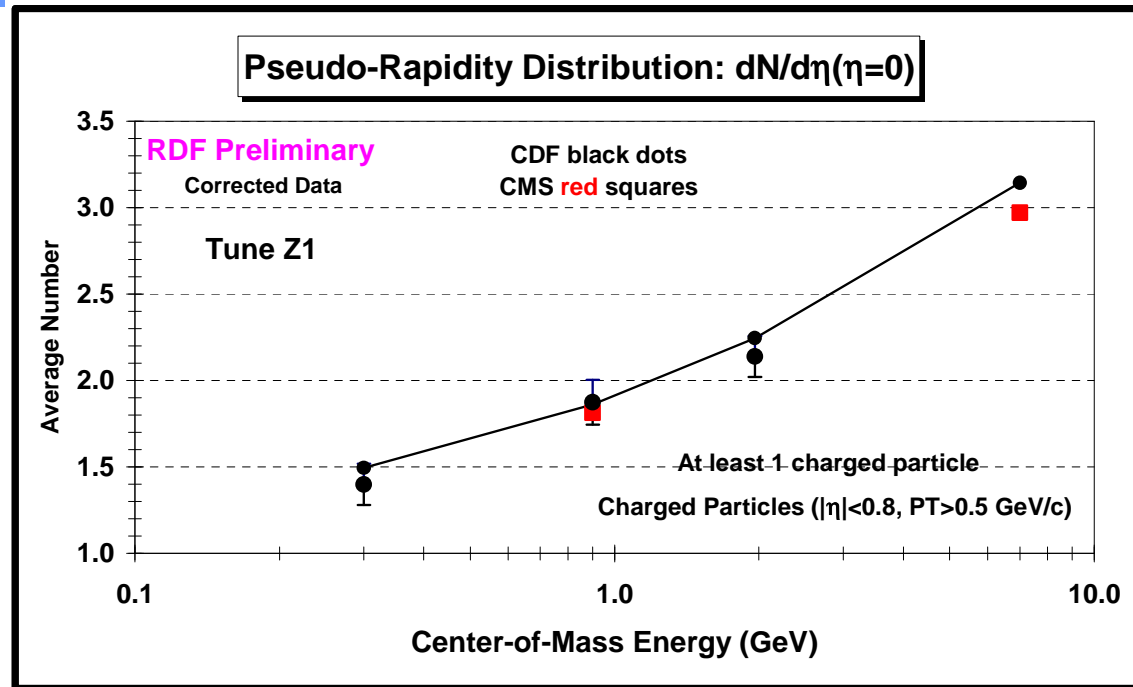
Energy Dependence $dN/d\eta$



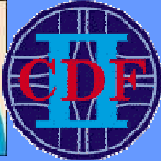
- **CMS** data at 7 TeV and 900 GeV and **CDF** data at 1.96 TeV, 900 GeV, and 300 GeV on $dN/d\eta$ at $\eta = 0$ with $p_T > 0.5$ GeV/c as a function of the center-of-mass energy. Events are required to have at least one charged particle with $|\eta| < 0.8$ and $p_T > 0.5$ GeV/c. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.



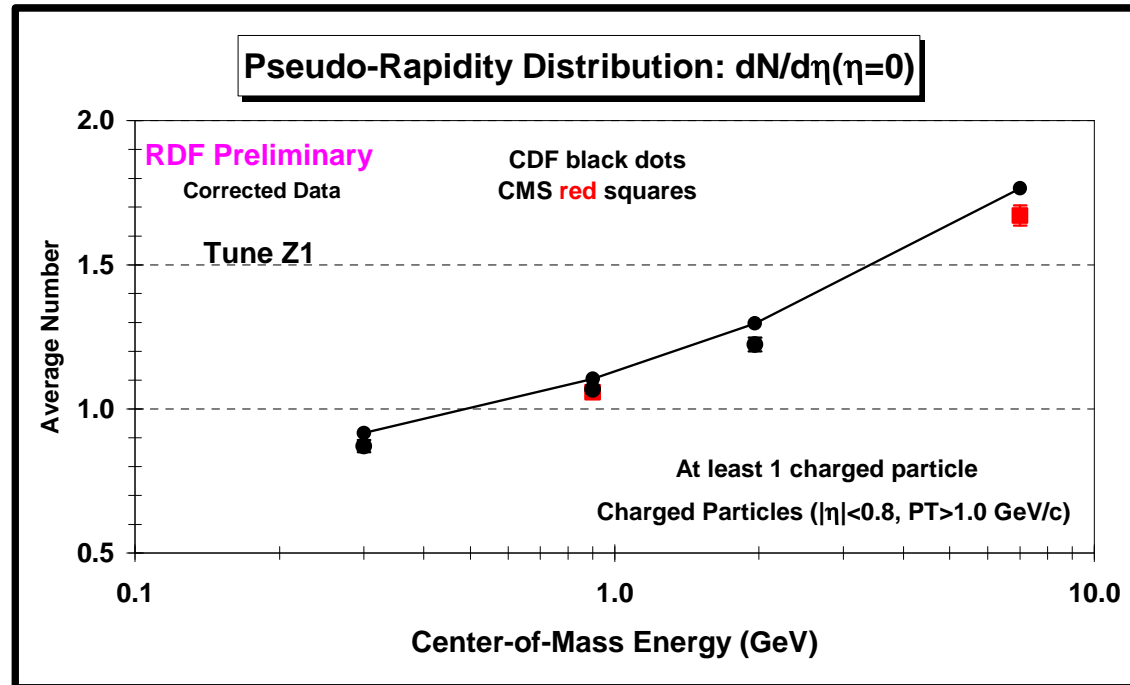
Energy Dependence $dN/d\eta$



- **CMS** data at 7 TeV and 900 GeV and **CDF** data at 1.96 TeV, 900 GeV, and 300 GeV on $dN/d\eta$ at $\eta = 0$ with $p_T > 0.5$ GeV/c as a function of the center-of-mass energy. Events are required to have at least one charged particle with $|\eta| < 0.8$ and $p_T > 0.5$ GeV/c. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.



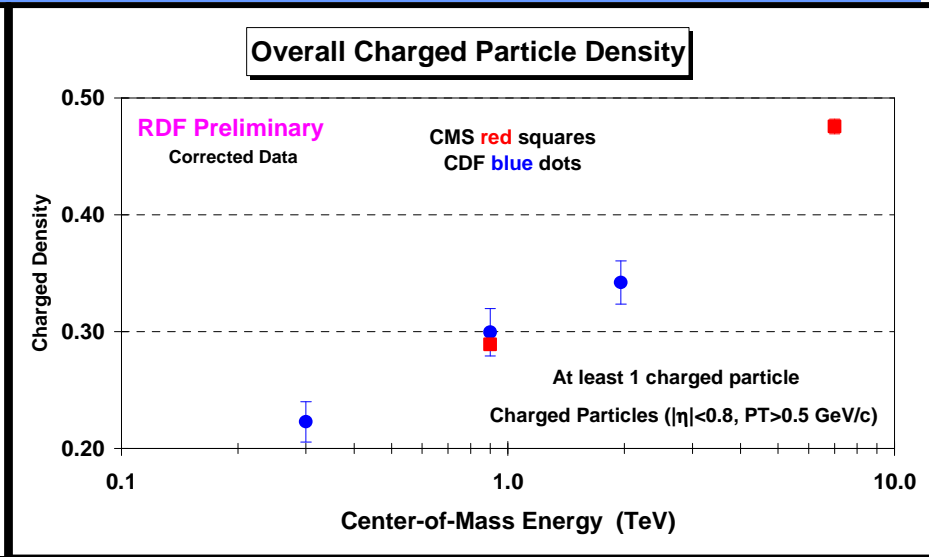
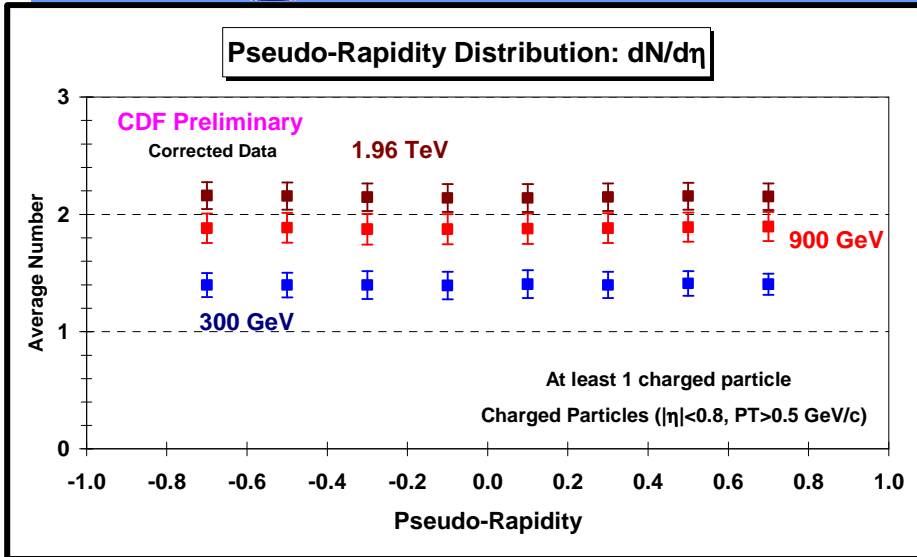
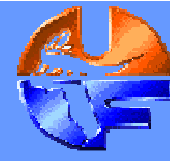
Energy Dependence $dN/d\eta$



- **CMS** data at 7 TeV and 900 GeV and **CDF** data at 1.96 TeV, 900 GeV, and 300 GeV on $dN/d\eta$ at $\eta = 0$ with $p_T > 1.0 \text{ GeV}/c$ as a function of the center-of-mass energy. Events are required to have at least one charged particle with $|\eta| < 0.8$ and $p_T > 1.0 \text{ GeV}/c$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.



Overall Charged Particle Density



➔ **Corrected CDF data** on the pseudo-rapidity distribution, $dN/d\eta$, for charged with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$.

➔ **Corrected CDF and CMS data** overall density of charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ plotted versus the center-of-mass energy (*log scale*). The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

Ecm	Nchg	error	NchgDen	error
300 GeV	2.241	0.175	0.223	0.017
900 GeV	3.012	0.203	0.300	0.020
1.96 TeV	3.439	0.186	0.342	0.019

$$N_{chg} = \int_{-0.8}^{0.8} \frac{dN}{d\eta} d\eta$$



UE Observables

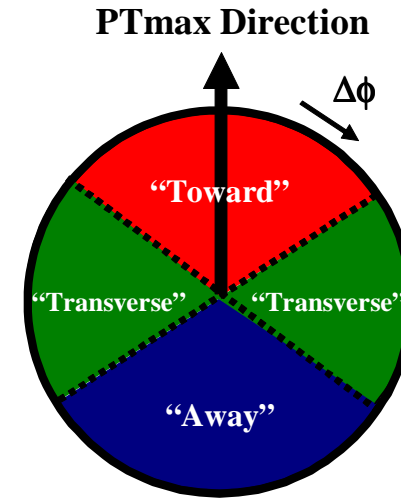


➔ **“Transverse” Charged Particle Density:** Number of charged particles ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$) in the “transverse” region as defined by the leading charged particle, PTmax, divided by the area in η - ϕ space, $2\eta_{\text{cut}} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$.

➔ **“Transverse” Charged PTsum Density:** Scalar p_T sum of the charged particles ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$) in the “transverse” region as defined by the leading charged particle, PTmax, divided by the area in η - ϕ space, $2\eta_{\text{cut}} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$.

➔ **“Transverse” Charged Particle Average p_T :** Event-by-event $\langle p_T \rangle = \text{PTsum}/N_{\text{chg}}$ for charged particles ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$) in the “transverse” region as defined by the leading charged particle, PTmax, averaged over all events with at least one particle in the “transverse” region with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$.

➔ **Zero “Transverse” Charged Particles:** If there are no charged particles in the “transverse” region then N_{chg} and PTsum are zero and one includes these zeros in the average over all events with at least one particle with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$. However, if there are no charged particles in the “transverse” region then the event is not used in constructing the “transverse” average p_T .



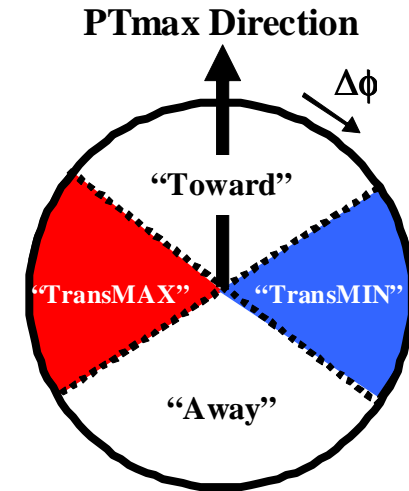
$$\eta_{\text{cut}} = 0.8$$



New UE Observables



- ➔ **“transMAX” and “transMIN” Charged Particle Density:** Number of charged particles ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < 0.8$) in the the maximum (minimum) of the two “transverse” regions as defined by the leading charged particle, PT_{max} , divided by the area in η - ϕ space, $2\eta_{\text{cut}} \times 2\pi/6$, averaged over all events with at least one particle with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$.
- ➔ **“transMAX” and “transMIN” Charged PT_{sum} Density:** Scalar p_T sum of charged particles ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < 0.8$) in the the maximum (minimum) of the two “transverse” regions as defined by the leading charged particle, PT_{max} , divided by the area in η - ϕ space, $2\eta_{\text{cut}} \times 2\pi/6$, averaged over all events with at least one particle with $p_T > 0.5 \text{ GeV}/c$, $|\eta| < \eta_{\text{cut}}$.



Note: The overall “transverse” density is equal to the average of the “transMAX” and “TransMIN” densities. The “TransDIF” Density is the “transMAX” Density minus the “transMIN” Density

$$\text{“Transverse” Density} = \text{“transAVE” Density} = (\text{“transMAX” Density} + \text{“transMIN” Density})/2$$

$$\text{“TransDIF” Density} = \text{“transMAX” Density} - \text{“transMIN” Density}$$

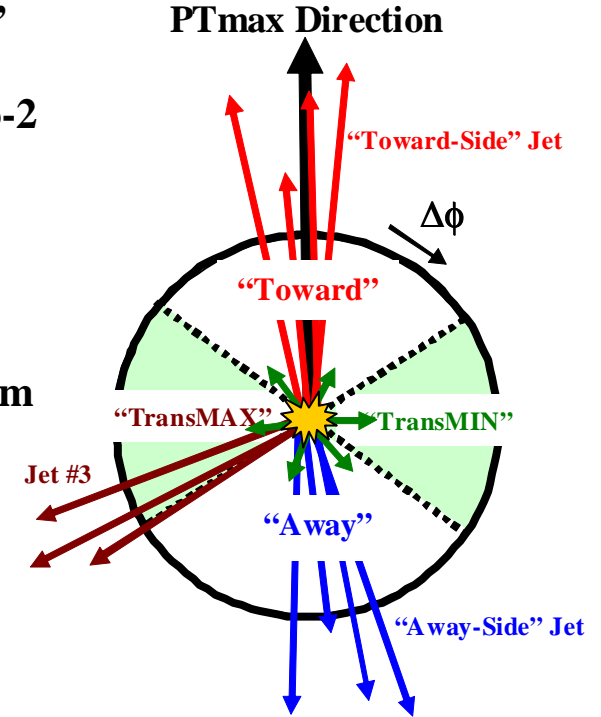
$$\eta_{\text{cut}} = 0.8$$



“transMIN” & “transDIF”



➔ The “toward” region contains the leading “jet”, while the “away” region, on the average, contains the “away-side” “jet”. The “transverse” region is perpendicular to the plane of the hard 2-to-2 scattering and is very sensitive to the “underlying event”. For events with large initial or final-state radiation the “transMAX” region defined contains the third jet while both the “transMAX” and “transMIN” regions receive contributions from the MPI and beam-beam remnants. Thus, the “transMIN” region is very sensitive to the multiple parton interactions (MPI) and beam-beam remnants (BBR), while the “transMAX” minus the “transMIN” (*i.e.* “transDIF”) is very sensitive to initial-state radiation (ISR) and final-state radiation (FSR).



“TransMIN” density more sensitive to MPI & BBR.

“TransDIF” density more sensitive to ISR & FSR.

$$0 \leq \text{“TransDIF”} \leq 2 \times \text{“TransAVE”}$$

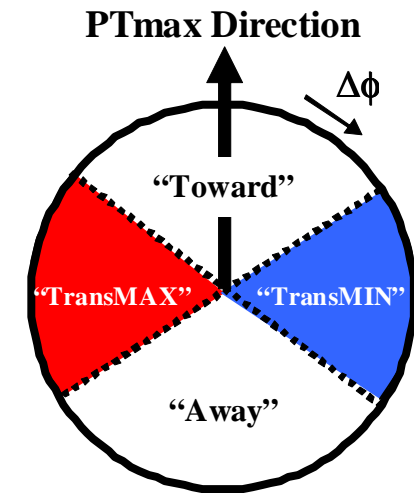
$$\text{“TransDIF”} = \text{“TransAVE”} \text{ if } \text{“TransMIX”} = 3 \times \text{“TransMIN”}$$



PTmax UE Data

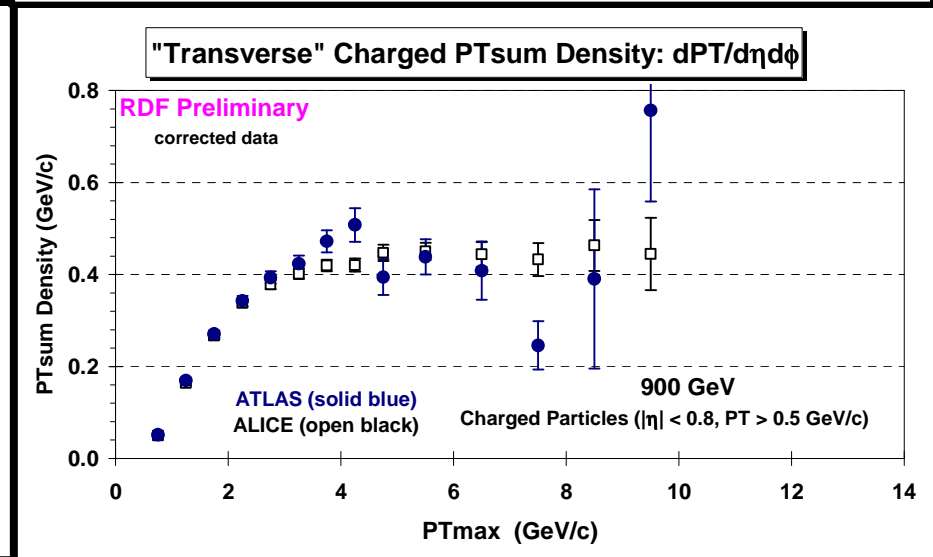
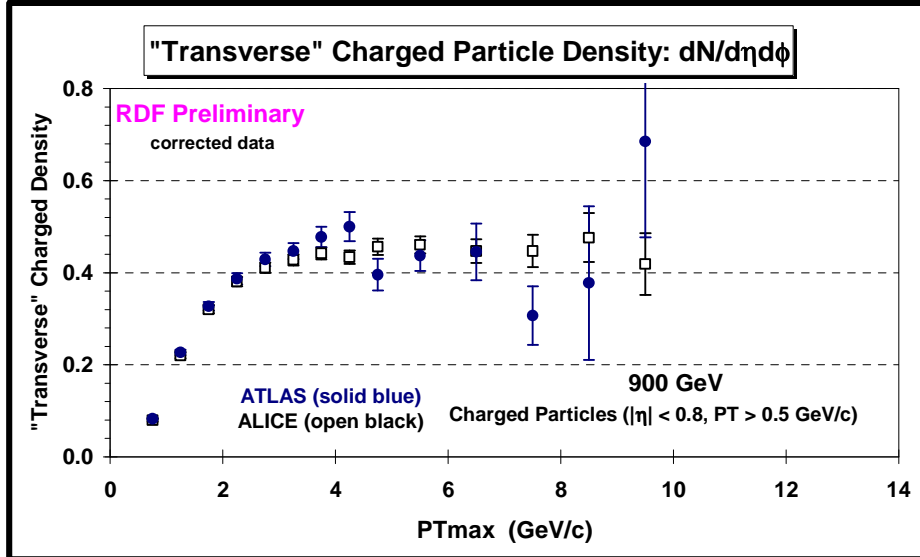
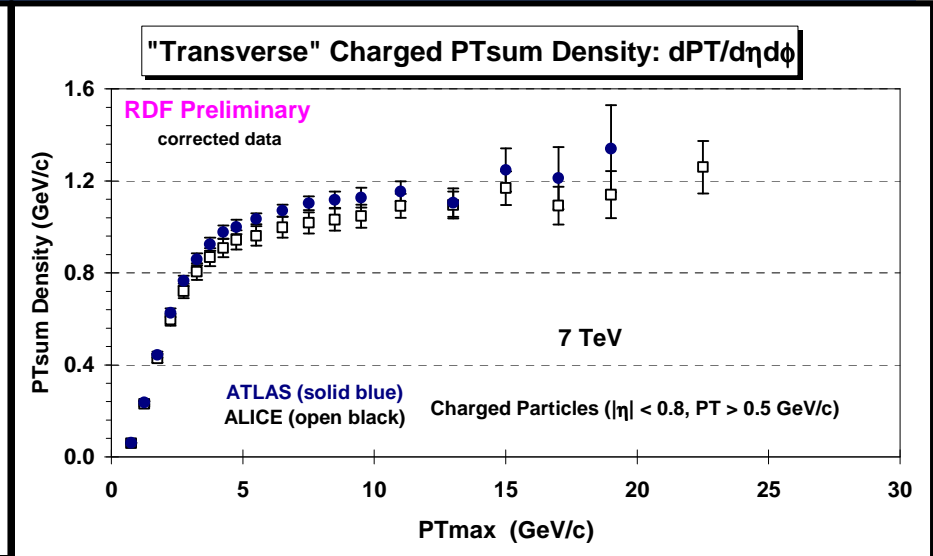
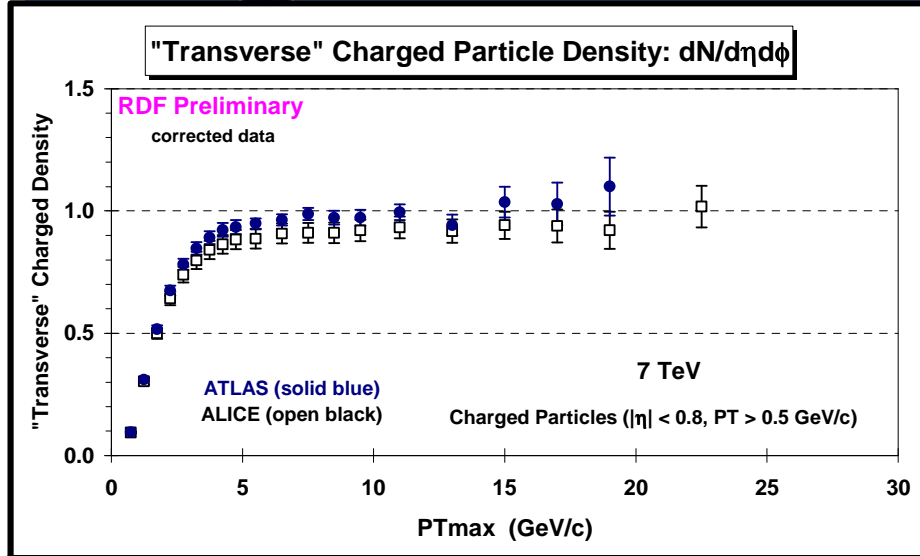


- ➔ **CDF PTmax UE Analysis:** “transMAX”, “transMIN”, “transAVE”, and “transDIF” charged particle and PTsum densities ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < 0.8$) in proton-antiproton collisions at 300 GeV, 900 GeV, and 1.96 TeV (R. Field analysis).
- ➔ **CMS PTmax UE Analysis:** “transMAX”, “transMIN”, “transAVE”, and “transDIF” charged particle and PTsum densities ($p_T > 0.5 \text{ GeV}/c$, $|\eta| < 0.8$) in proton-proton collisions at 900 GeV and 7 TeV (M. Zakaria analysis). The “transMAX”, “transMIN”, and “transDIF” are not yet approved so I can only show “transAVE” which is approved.
- ➔ **CMS UE Tunes:** PYTHIA 6.4 Tune Z1 (CTEQ5L) and PYTHIA 6.4 Tune Z2* (CTEQ6L). Both were tuned to the CMS leading chgjet “transAVE” UE data at 900 GeV and 7 TeV.
- ➔ **PYTHIA 8:** Some comparisons with PYTHIA 8 Tune 4C (CTEQ6L), Richard Corke and Torbjörn Sjöstrand, JHEP 1103:032 (2011), arXiv:1011.1759.



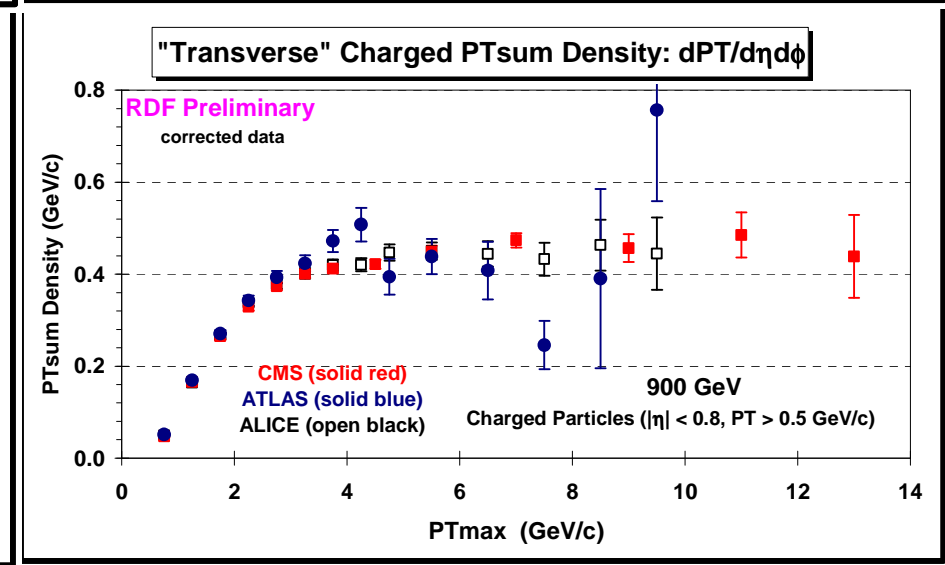
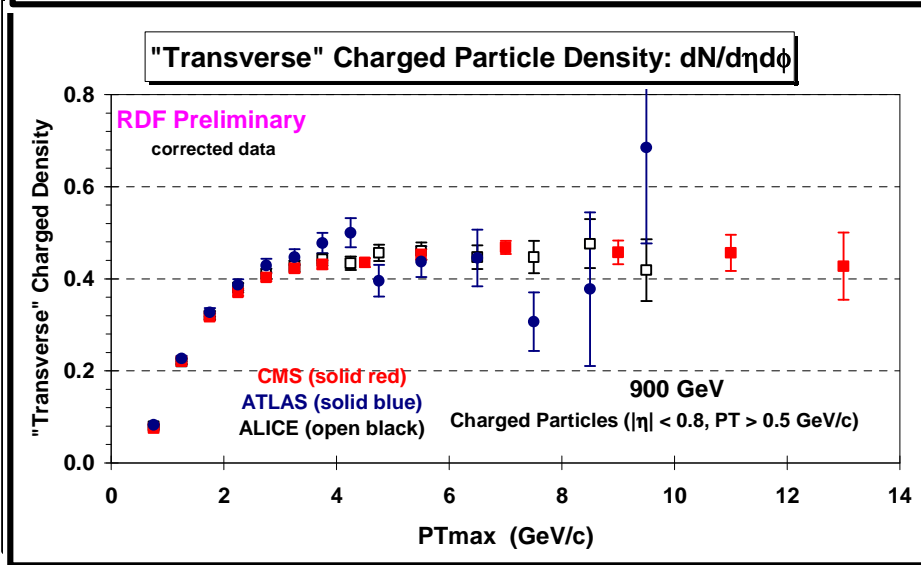
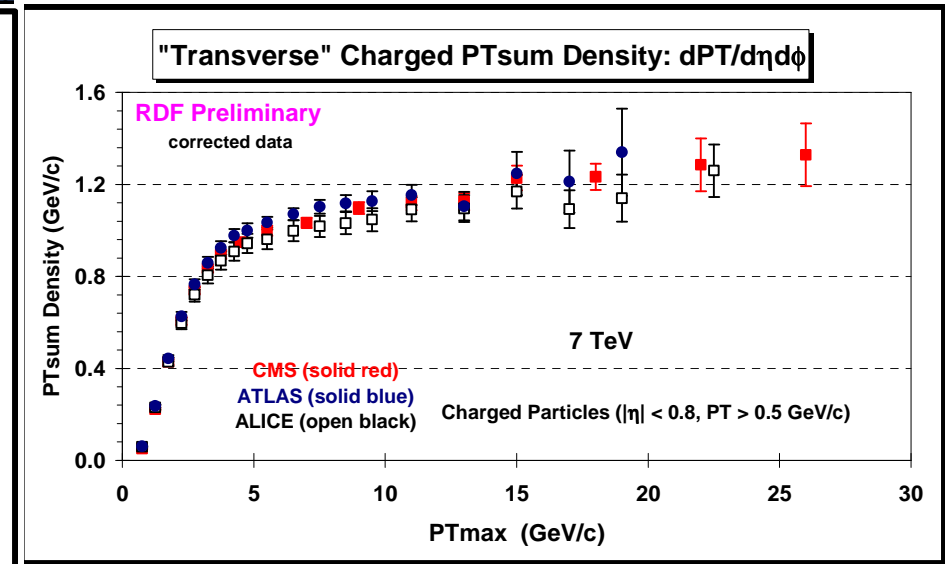
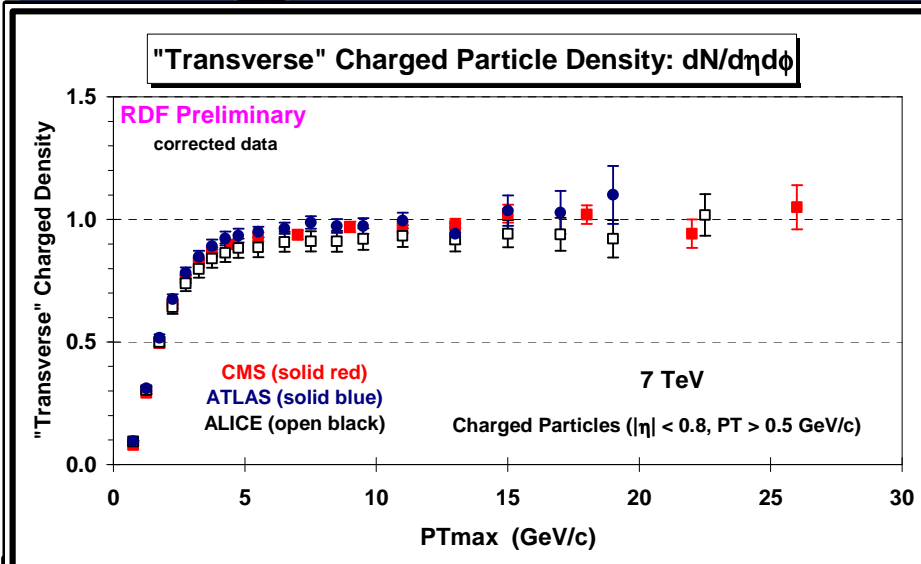
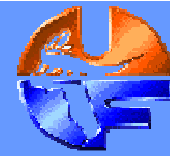


UE Common Plots



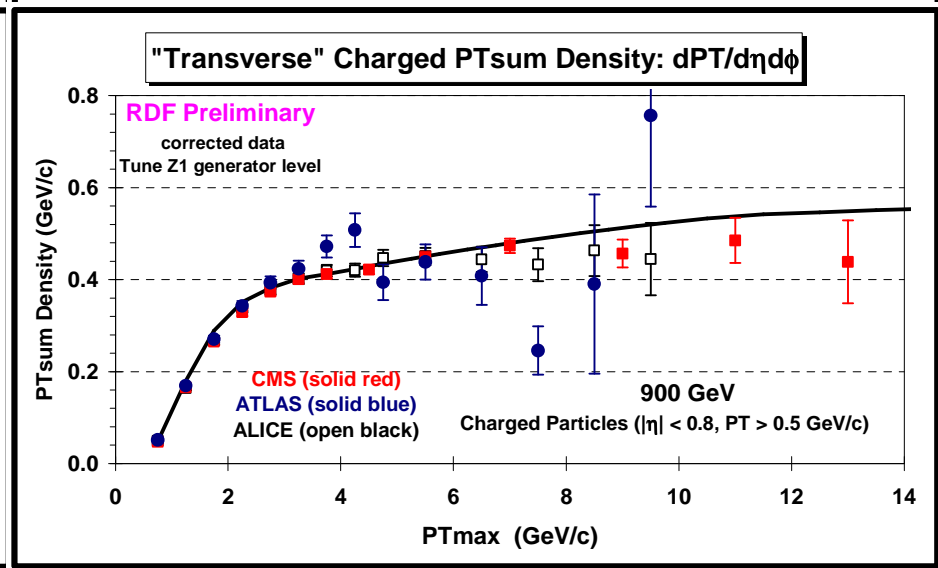
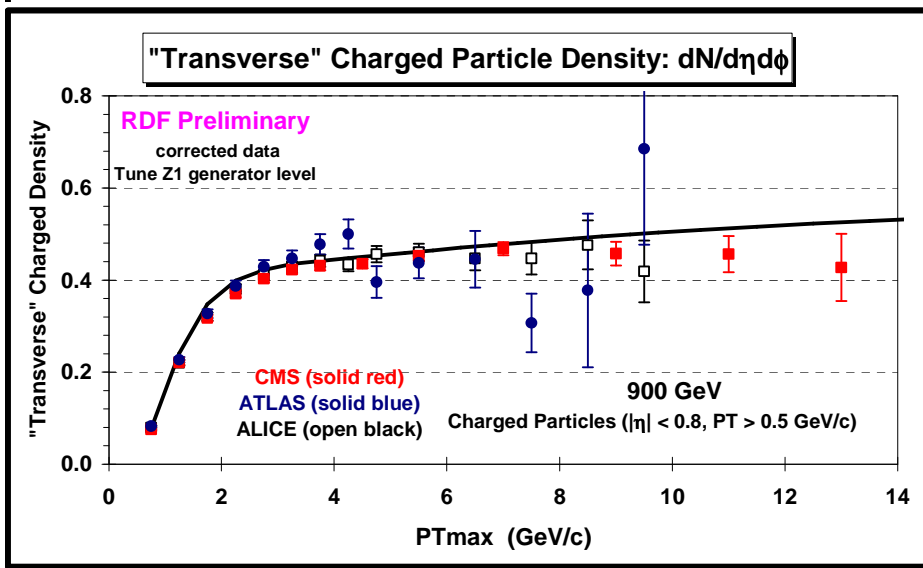
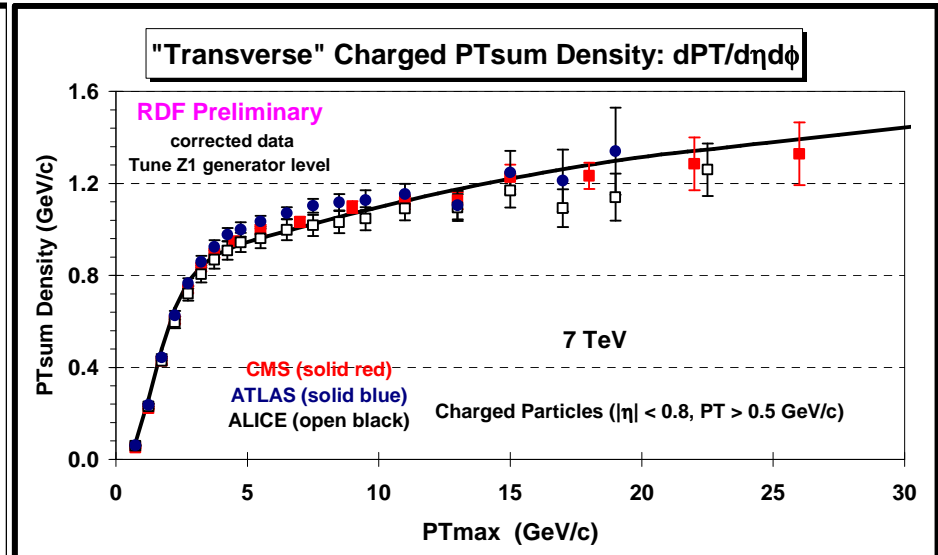
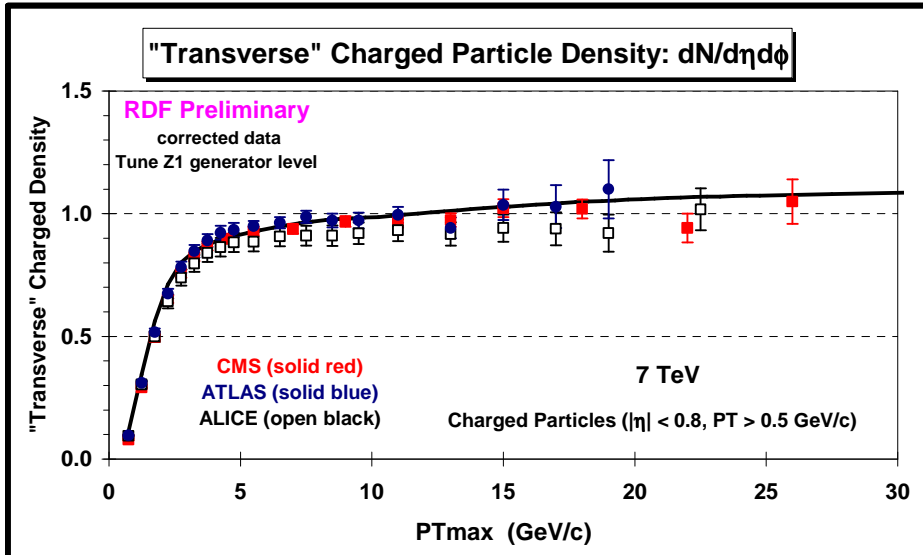
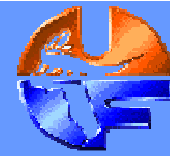


UE Common Plots



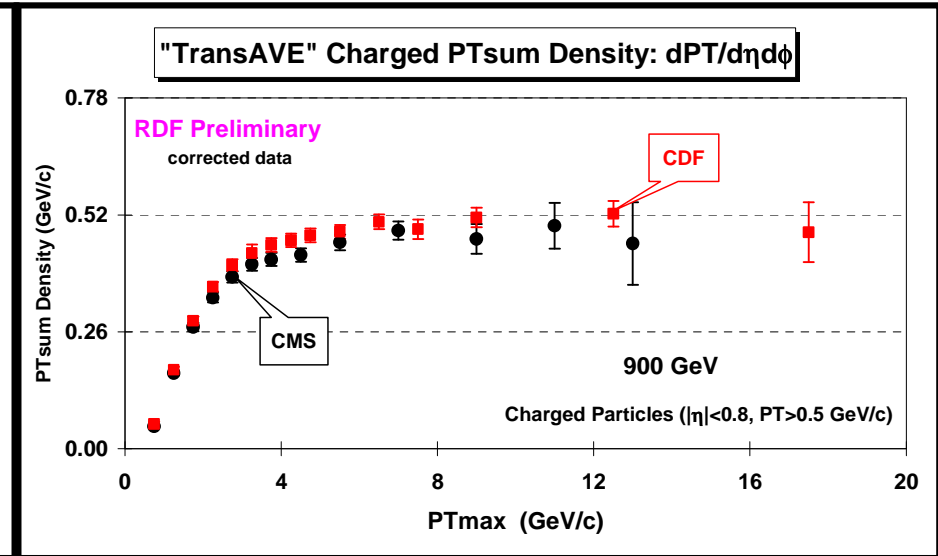
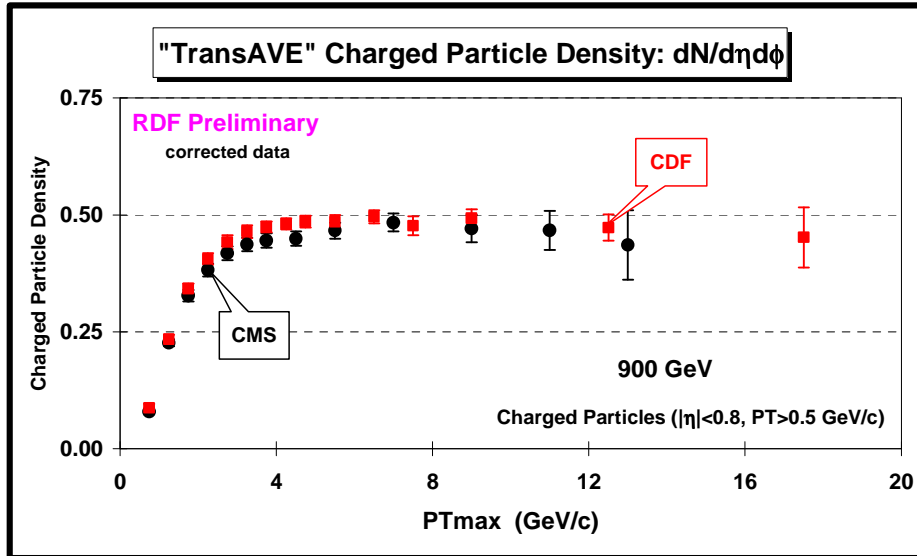


UE Common Plots





CDF versus LHC

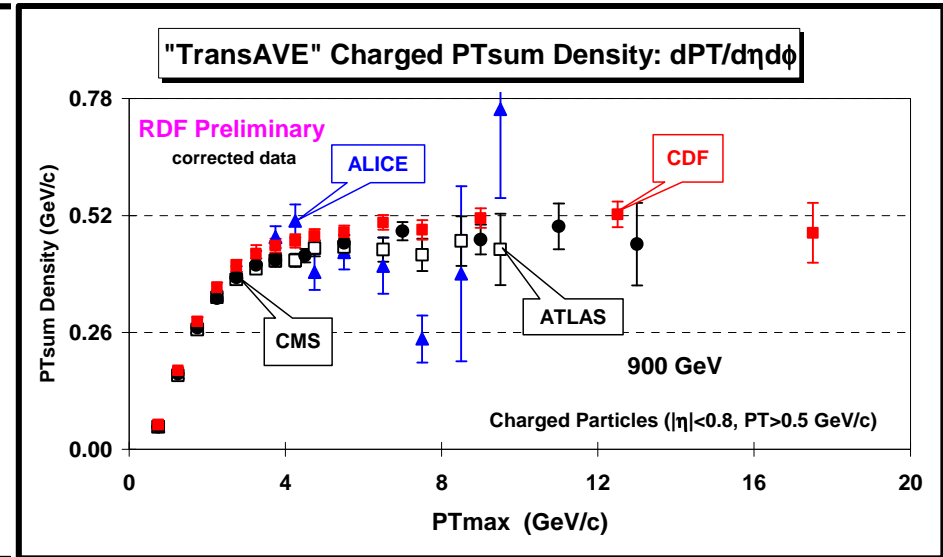
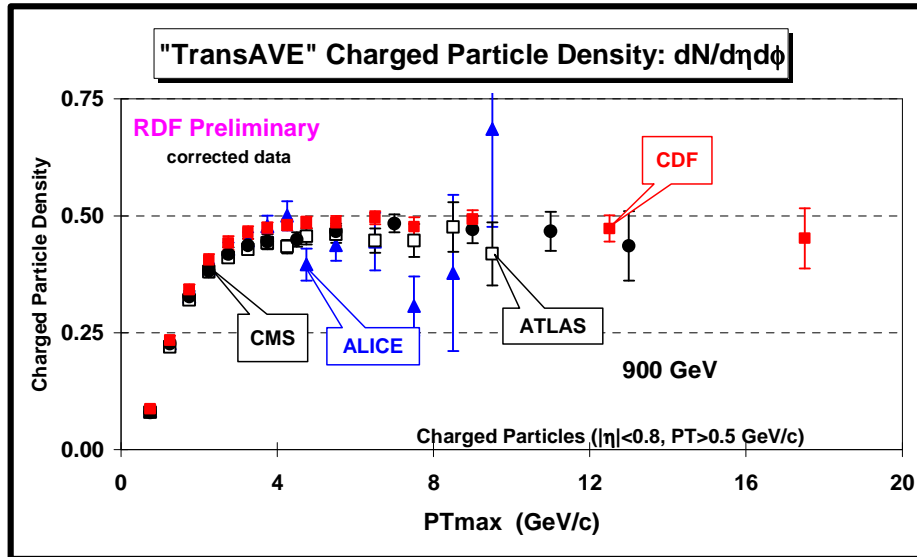


➔ **CDF and CMS data at 900 GeV/c** on the charged particle density in the “transverse” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

➔ **CDF and CMS data at 900 GeV/c** on the charged PTsum density in the “transverse” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.



CDF versus LHC

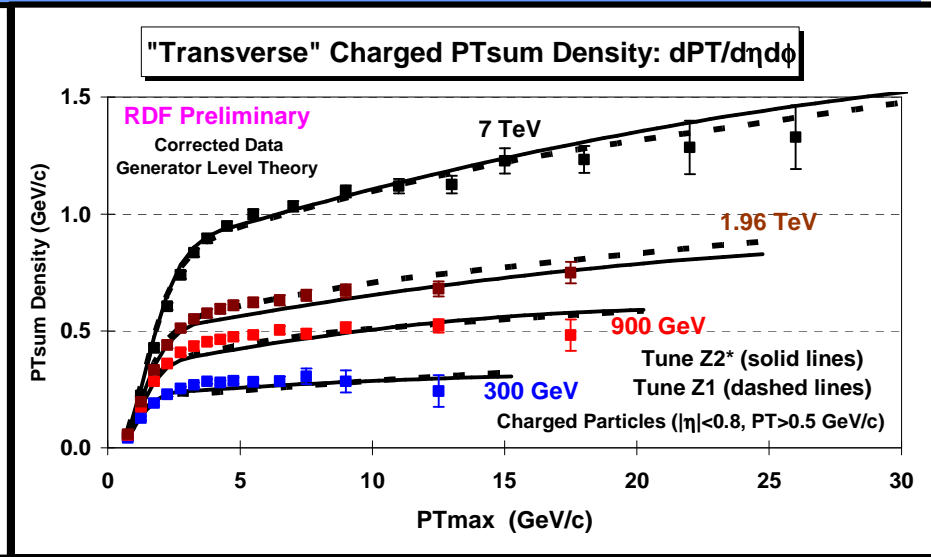
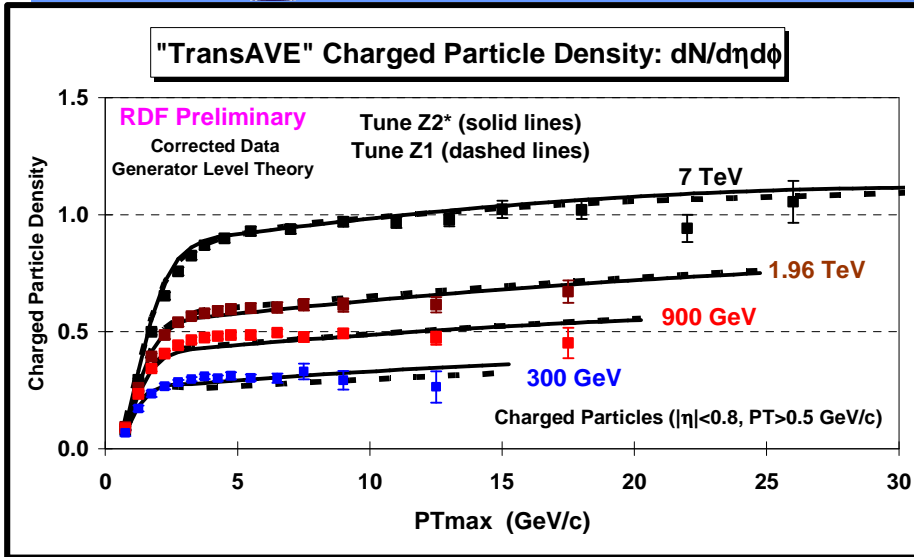


➔ **CDF and CMS data at 900 GeV/c** on the charged particle density in the “transverse” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

➔ **CDF and CMS data at 900 GeV/c** on the charged PTsum density in the “transverse” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.



“TransAVE” Density

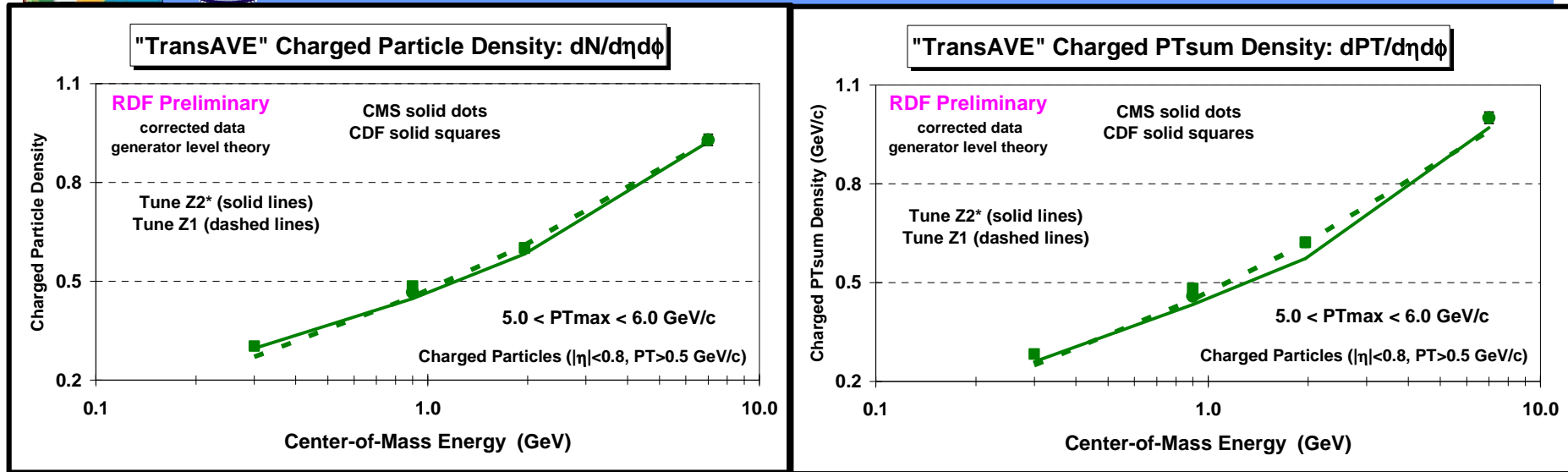
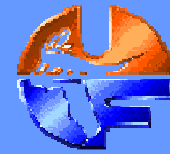


➔ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transAVE” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA **Tune Z1** and **Tune Z2***.**

➔ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the “transAVE” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA **Tune Z1** and **Tune Z2***.**



“TransAVE” vs E_{cm}

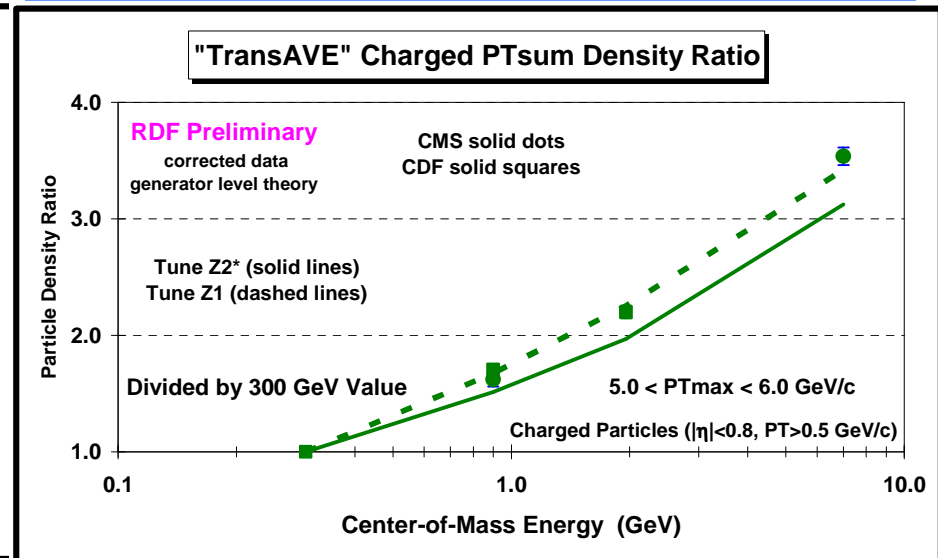
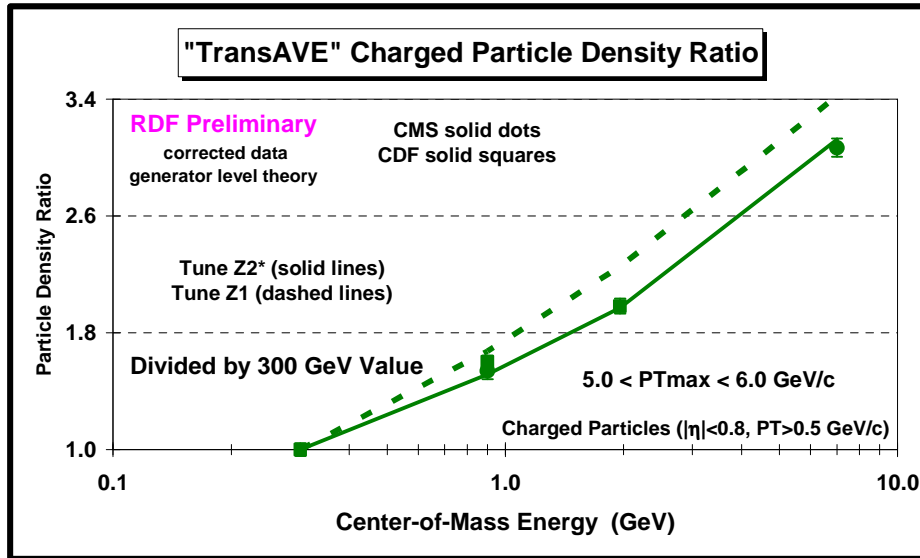
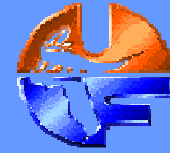


➔ **Corrected CMS data at 900 GeV and 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “**transAVE**” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.

➔ **Corrected CMS data at 900 GeV and 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged PTsum density in the “**transAVE**” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.



“TransAVE” vs E_{cm}



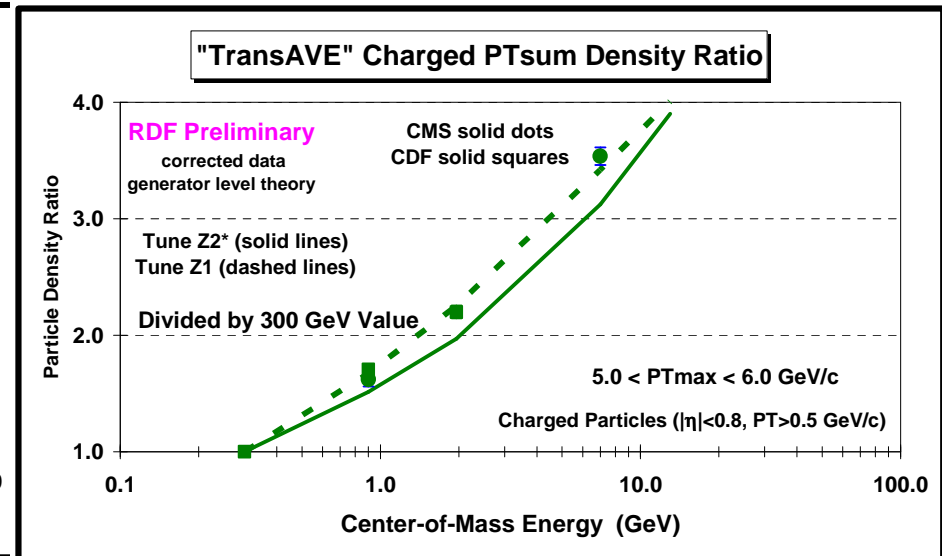
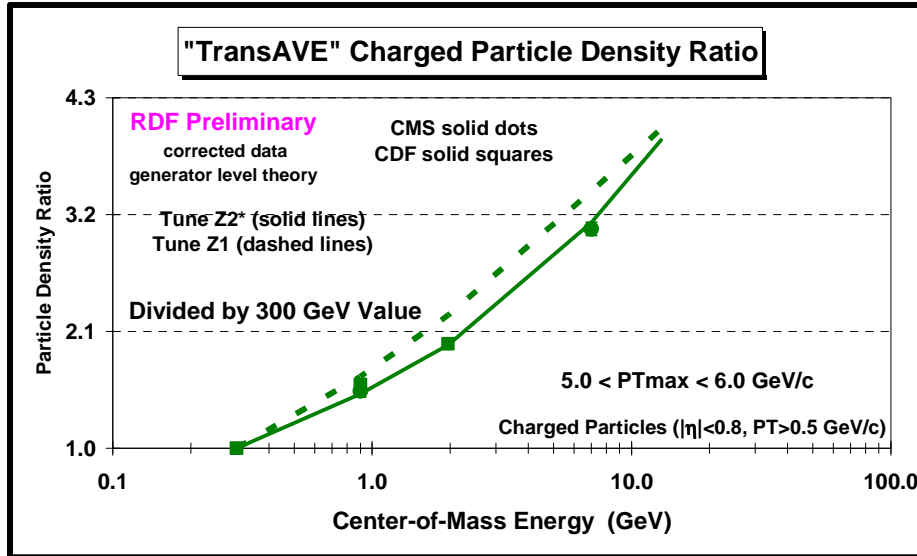
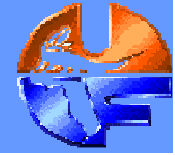
➔ **Corrected CMS data at 900 GeV and 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “**transAVE**” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.

➔ **Corrected CMS data at 900 GeV and 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged PTsum density in the “**transAVE**” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.

The data are “normalized” by dividing by the corresponding value at 300 GeV.



“TransAVE” vs E_{cm}

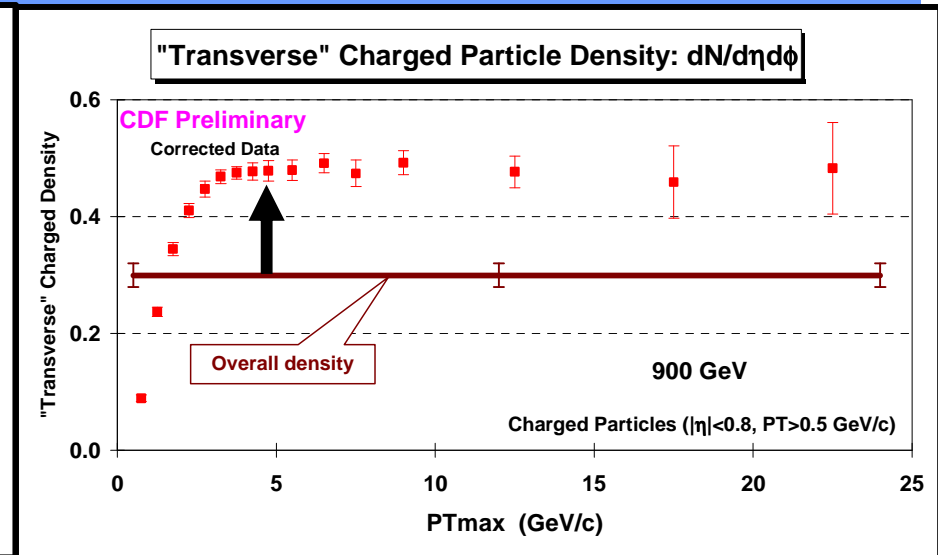
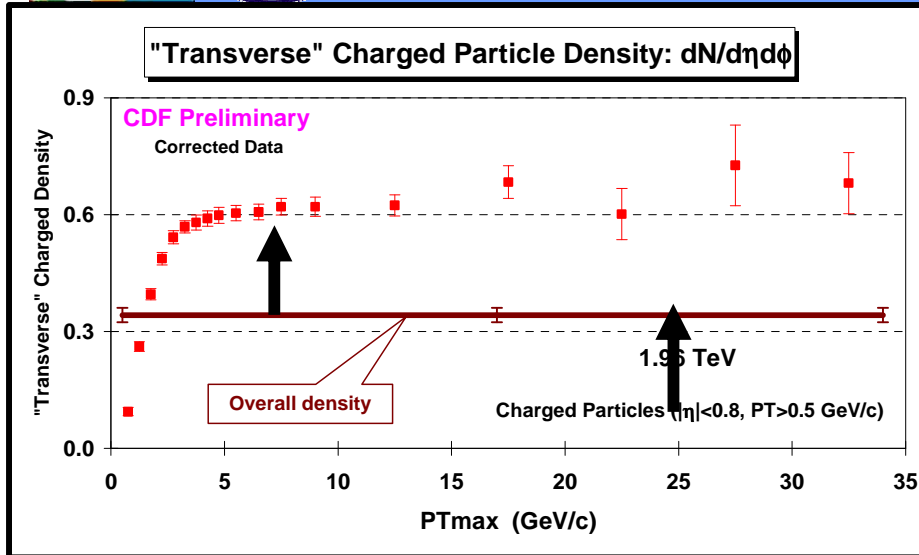


➔ **Corrected CMS data at 900 GeV and 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “**transAVE**” region as defined by the leading charged particle (PT_{max}) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PT_{max} < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.

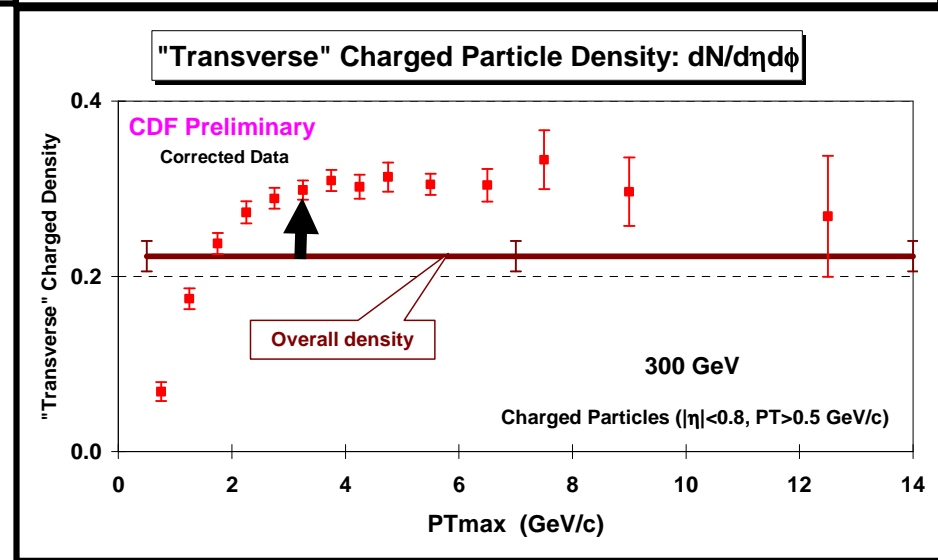
➔ **Corrected CMS data at 900 GeV and 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged PTsum density in the “**transAVE**” region as defined by the leading charged particle (PT_{max}) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PT_{max} < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.

The data are “normalized” by dividing by the corresponding value at 300 GeV.

MB versus the UE

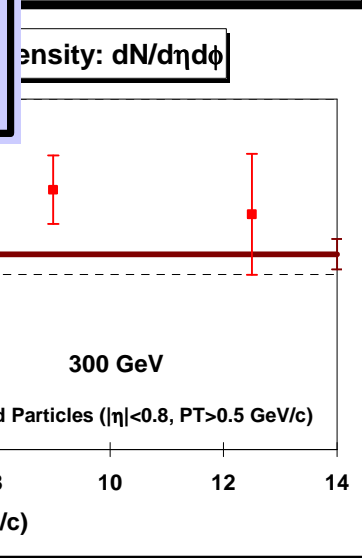
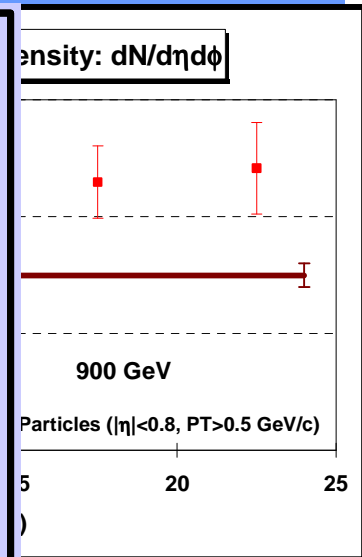
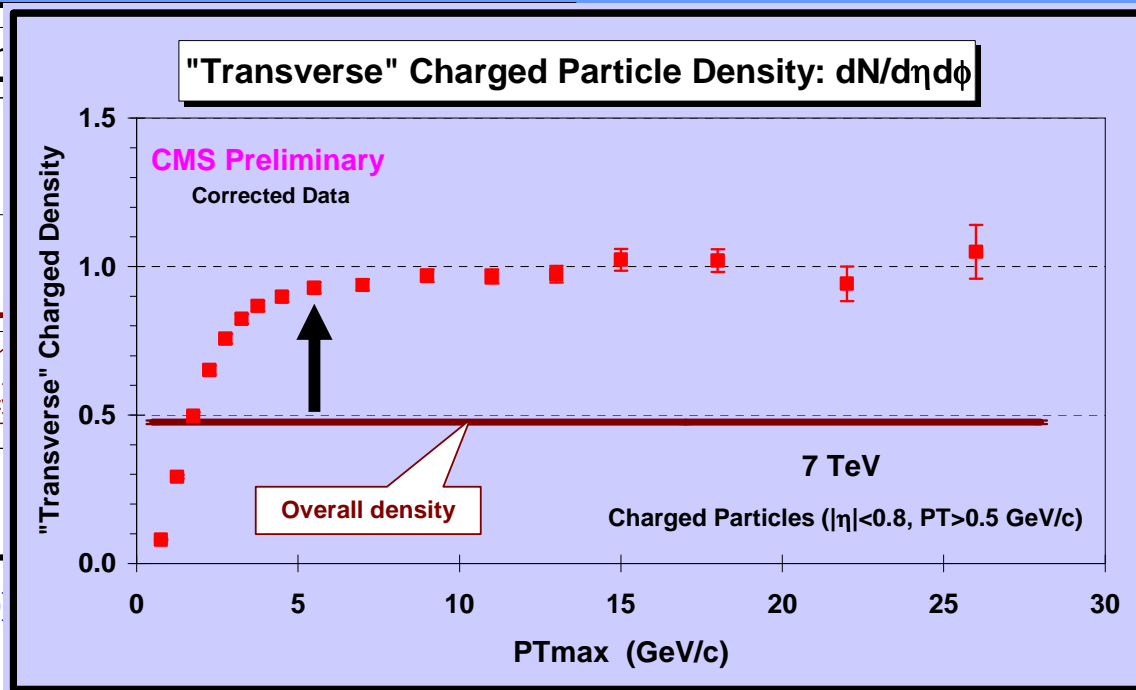
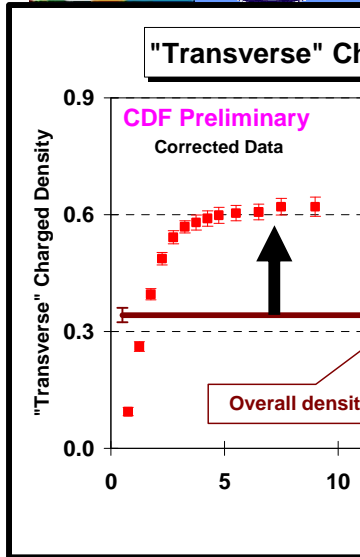
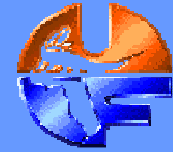


➔ **Corrected CDF data** on the charged particle density, in the “transverse” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty and are compared with the overall charged particle density (*straight lines*).





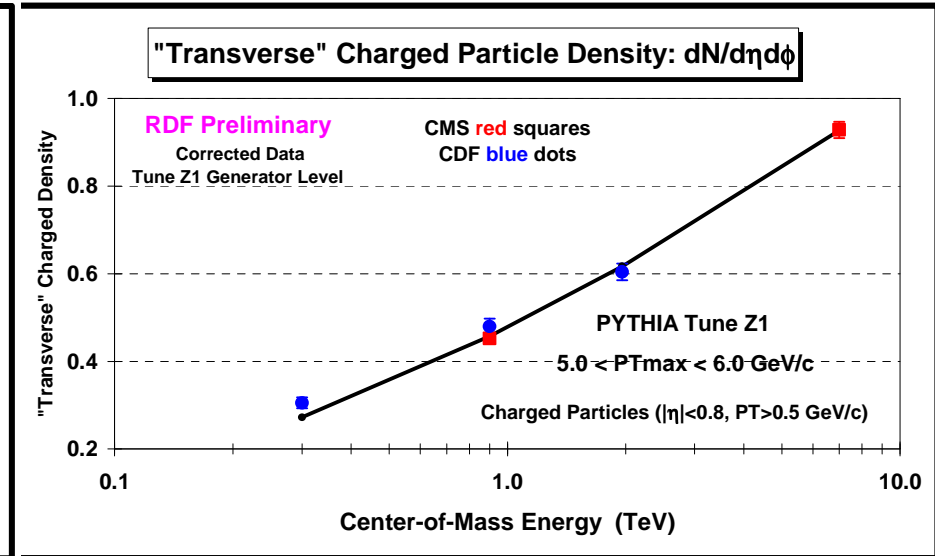
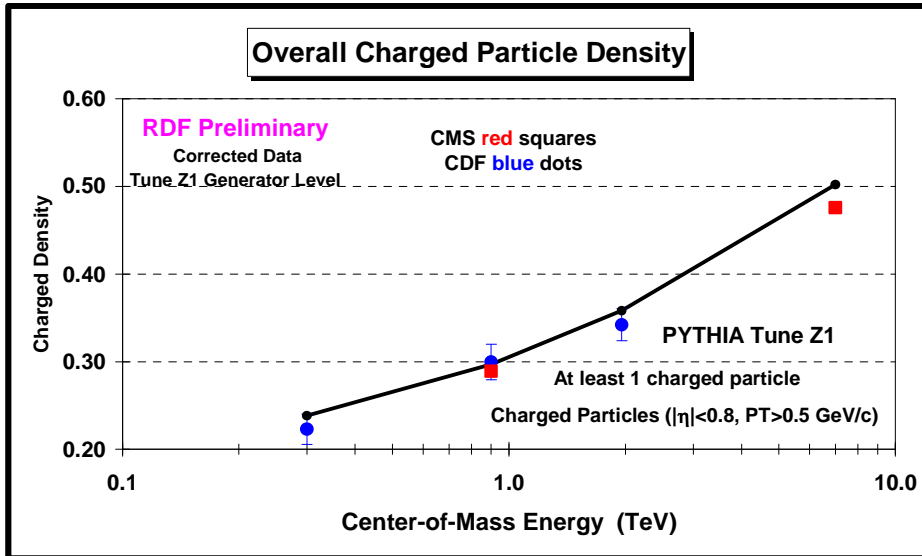
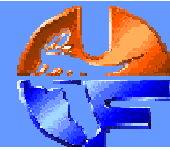
MB versus the UE



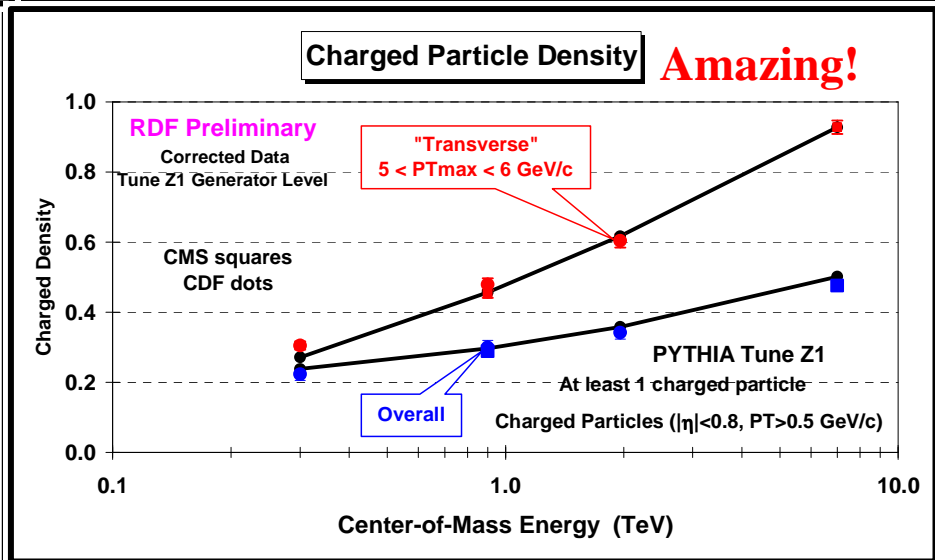
➔ **Corrected CD** density, in the defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty and are compared with the overall charged particle density (*straight lines*).

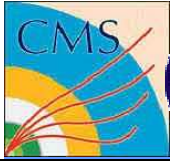


MB versus the UE

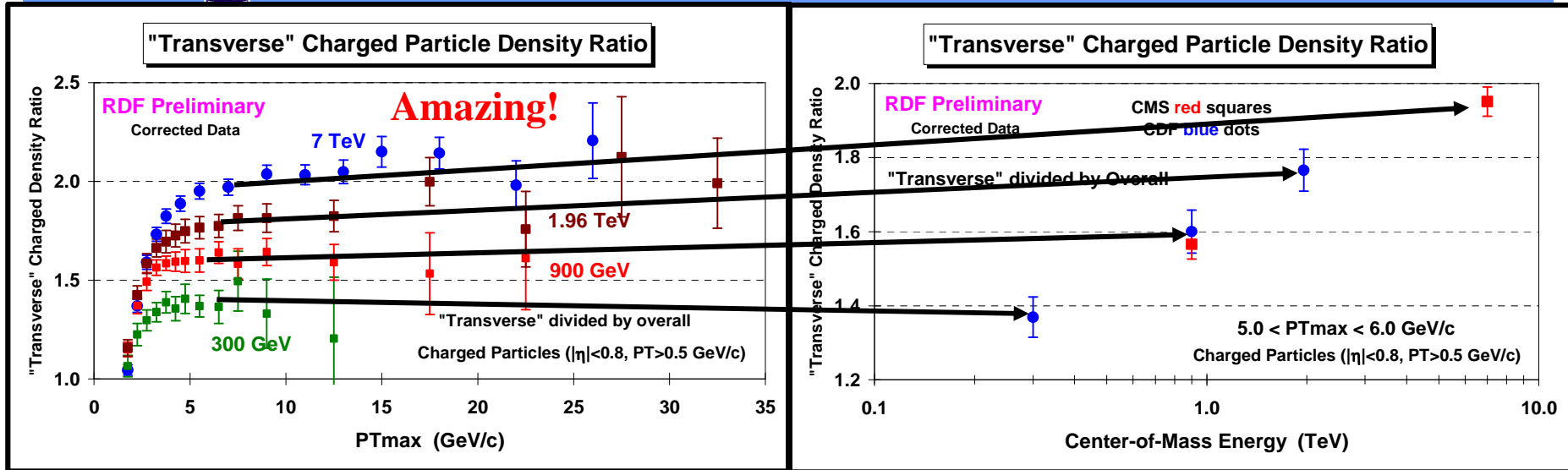
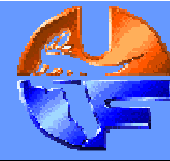


→ **Corrected CDF and CMS data** on the overall density of charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$ for events with at least one charged particle with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$ and on the charged particle density, in the "transverse" region as defined by the leading charged particle (p_{Tmax}) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$ with $5 < p_{Tmax} < 6 \text{ GeV}/c$. The data are plotted versus the center-of-mass energy (*log scale*).





“Transverse”/Overall

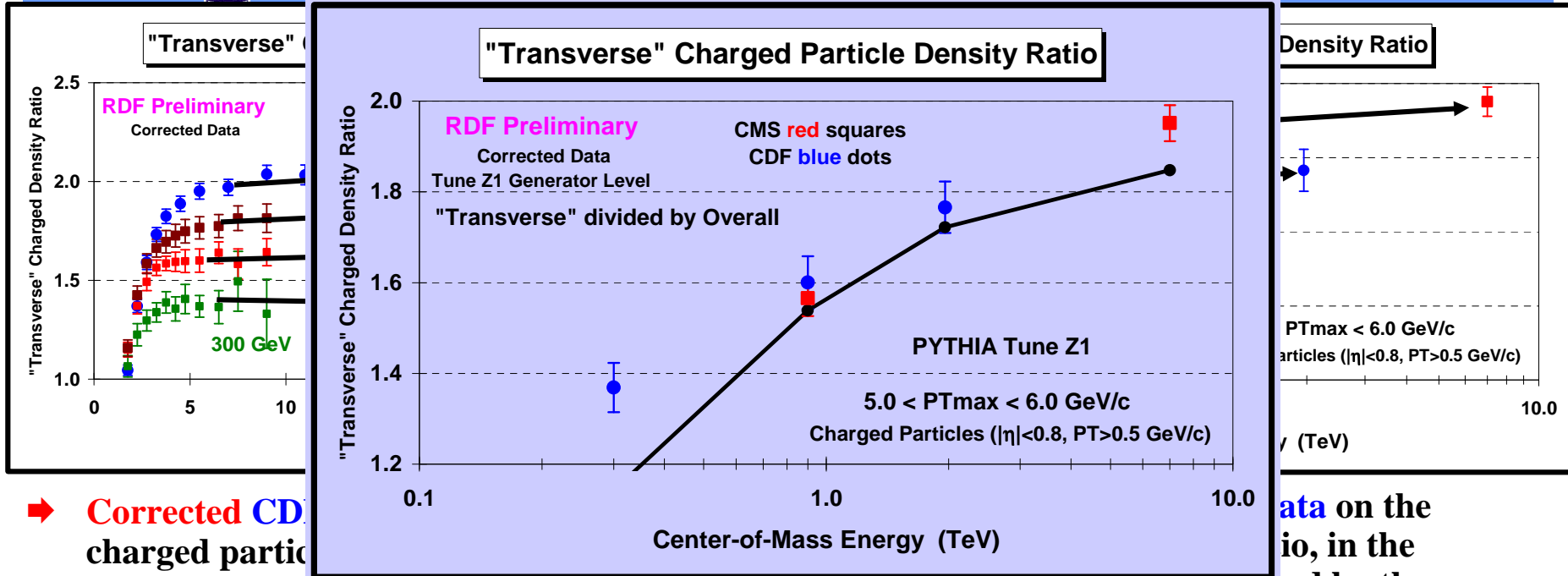


➔ **Corrected CDF and CMS data** on the charged particle density ratio, in the “transverse” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5 \text{ GeV/c}$ and $|\eta| < 0.8$. The ratio corresponds to the “transverse” charged particle density divided by the overall charged particle density ($N_{\text{chg}} \geq 1$).

➔ **Corrected CDF and CMS data** on the charged particle density ratio, in the “transverse” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5 \text{ GeV/c}$ and $|\eta| < 0.8$ for $5 < \text{PTmax} < 6 \text{ GeV/c}$. The ratio corresponds to the “transverse” charged particle density divided by the overall charged particle density ($N_{\text{chg}} \geq 1$). The data are plotted versus the center-of-mass energy (*log scale*).

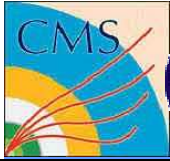


“Transverse”/Overall

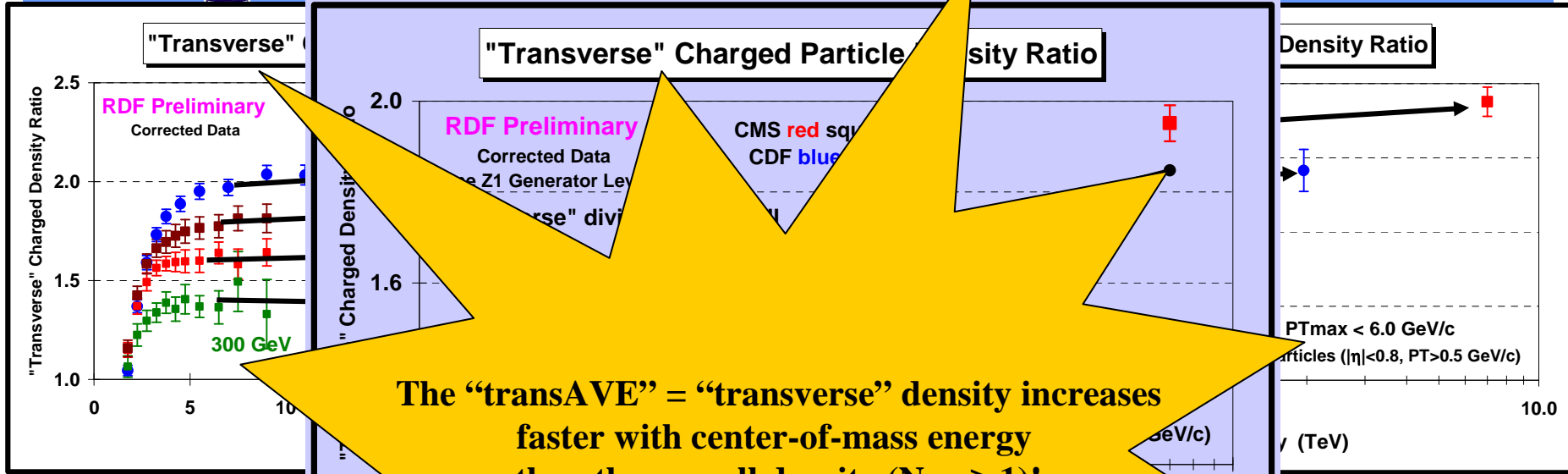
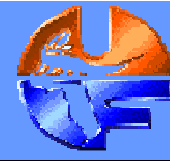


→ **Corrected CDF** data on the “transverse” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The ratio corresponds to the “transverse” charged particle density divided by the overall charged particle density ($N_{\text{chg}} \geq 1$).

data on the “transverse” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ for $5 < PT_{\text{max}} < 6$ GeV/c. The ratio corresponds to the “transverse” charged particle density divided by the overall charged particle density ($N_{\text{chg}} \geq 1$). The data are plotted versus the center-of-mass energy (log scale).



“Transverse”/Overall



The “transAVE” = “transverse” density increases faster with center-of-mass energy than the overall density ($N_{\text{chg}} \geq 1$)!

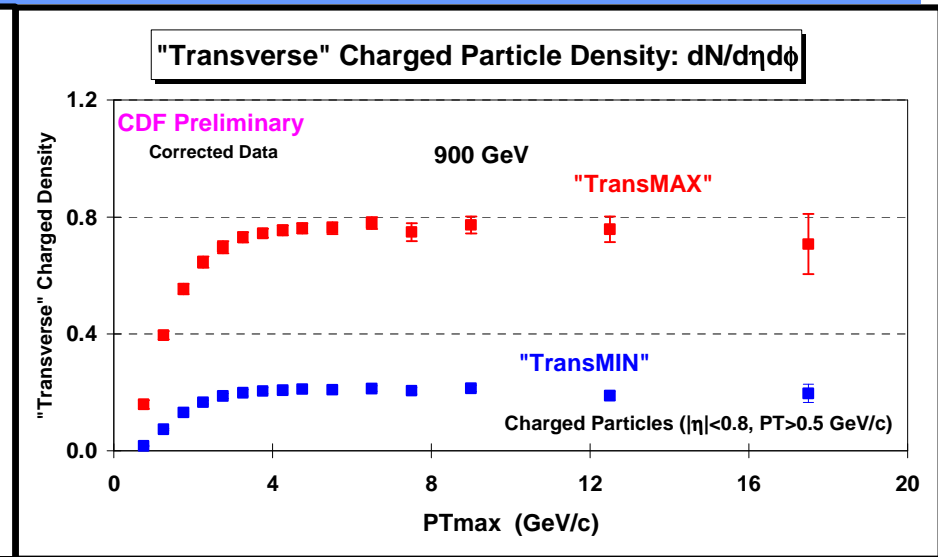
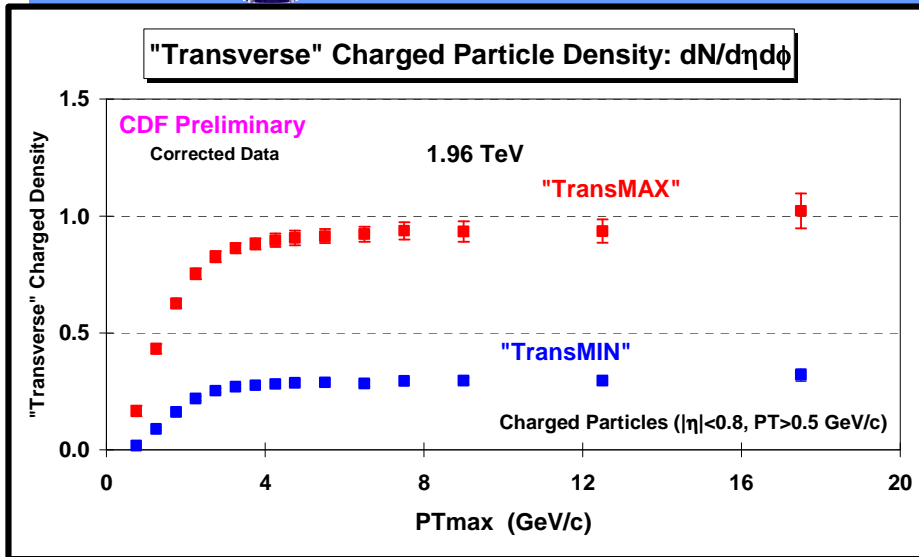
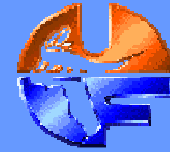
→ Corrected CDF

charged particle “transverse” region as defined by the leading charged particle (p_T of the most leading charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The ratio corresponds to the “transverse” charged particle density divided by the overall charged particle density ($N_{\text{chg}} \geq 1$).

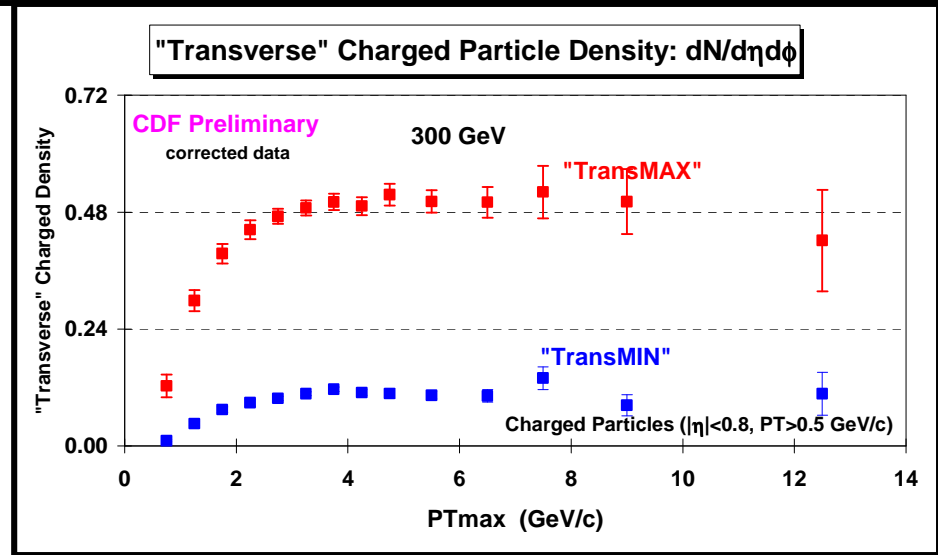
data on the ratio, in the region as defined by the leading charged particle (p_T of the most leading charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ for $p_T^{\text{max}} < 6$ GeV/c. The ratio corresponds to “transverse” charged particle density divided by the overall charged particle density ($N_{\text{chg}} \geq 1$). The data are plotted versus the center-of-mass energy (log scale).

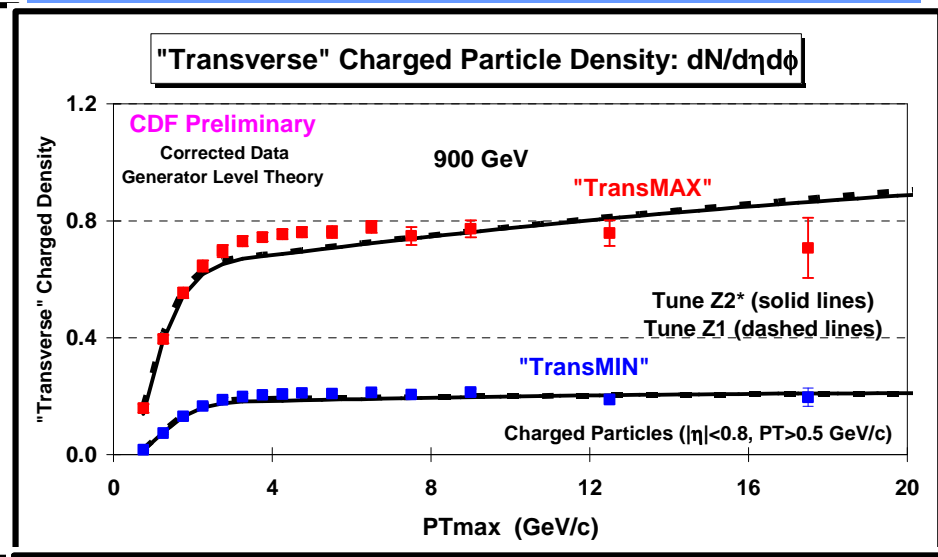
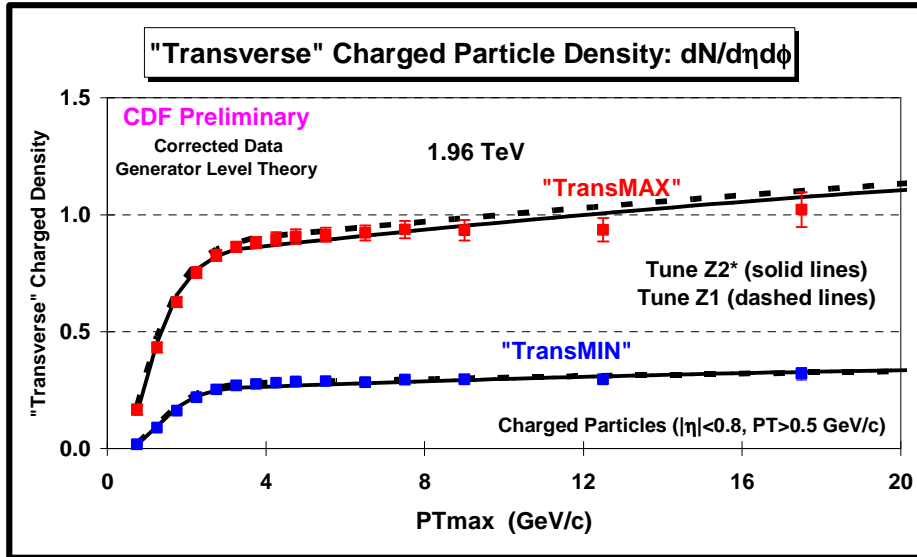


“transMAX/MIN” NchgDen



➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “transMAX” and “transMIN” regions as defined by the leading charged particle (P_{Tmax}) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

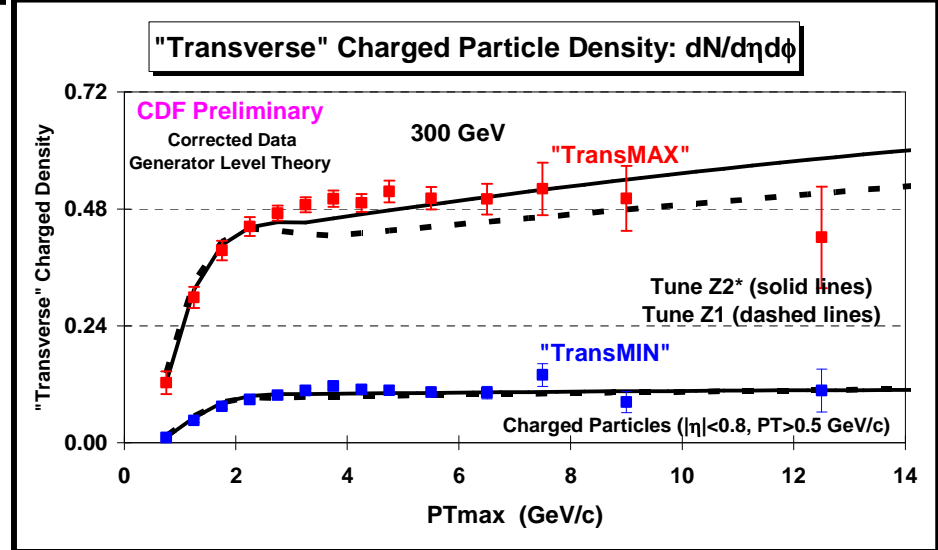


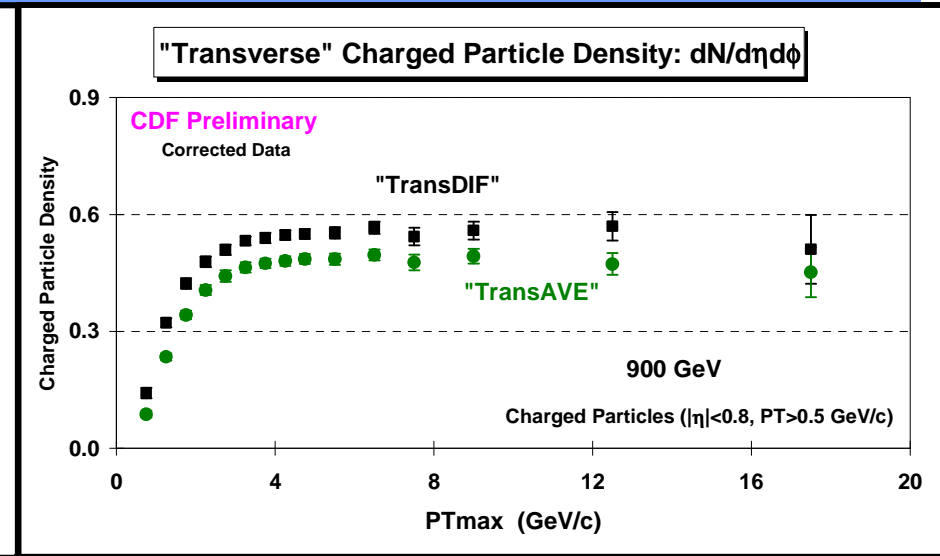
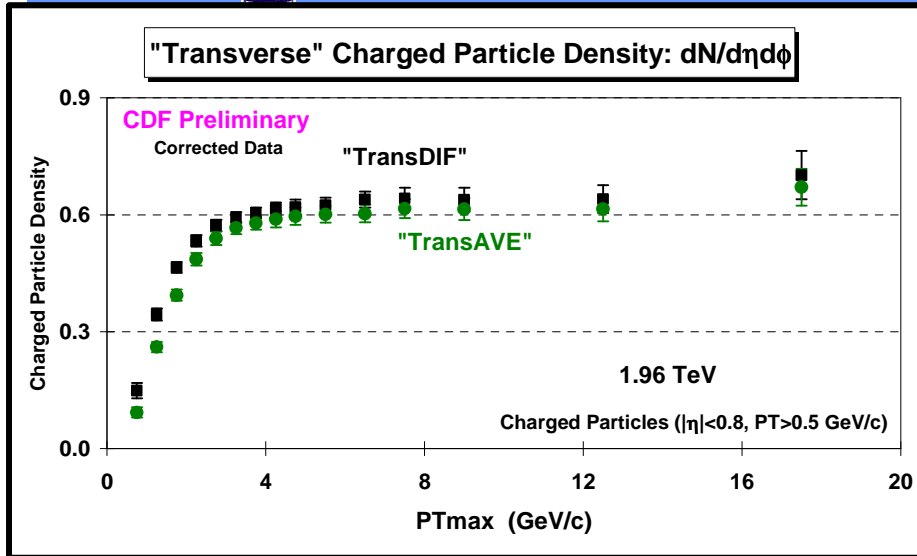


→ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “transMAX” and “transMIN” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

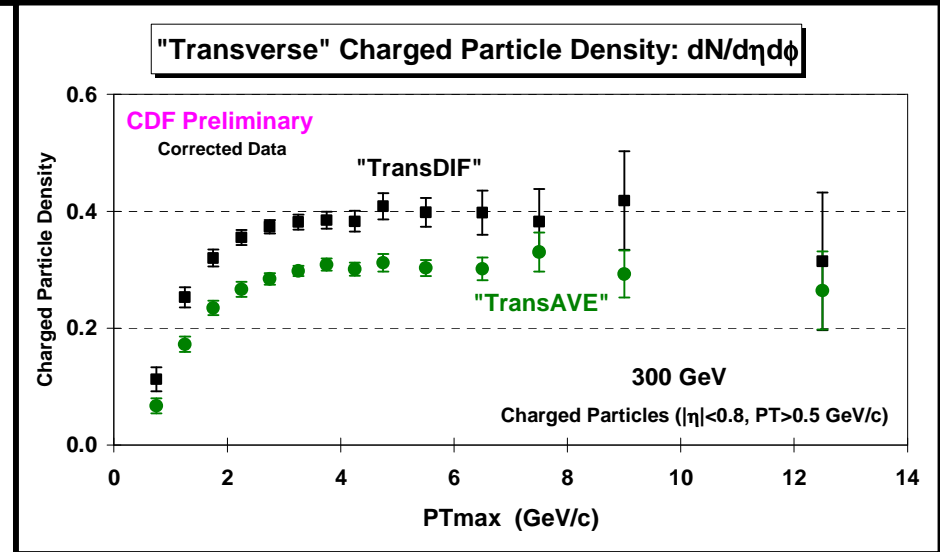
The data are compared with PYTHIA 6.4

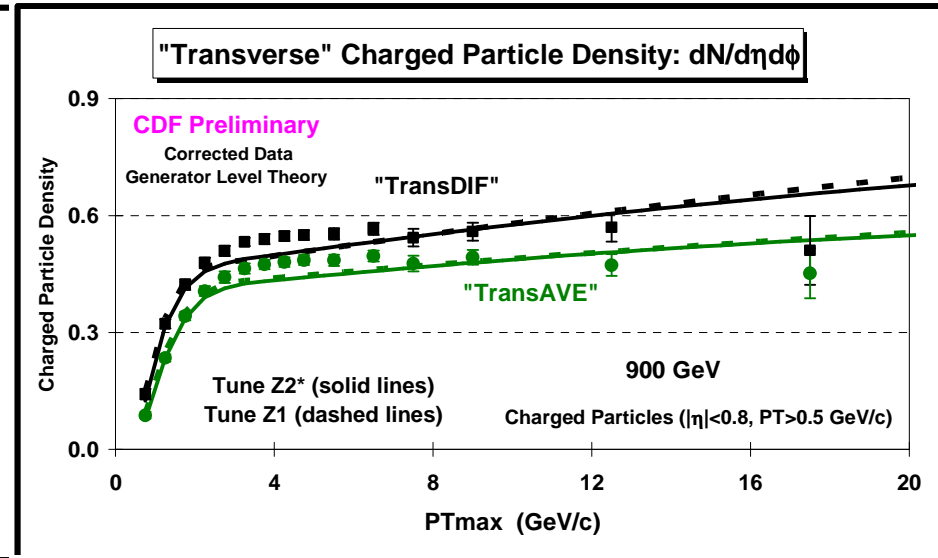
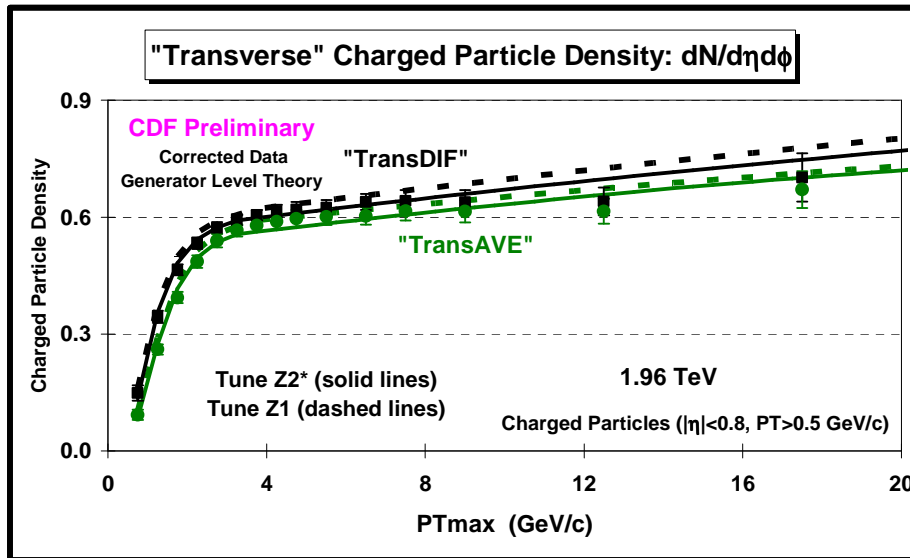
Tune Z1 and Tune Z2*.



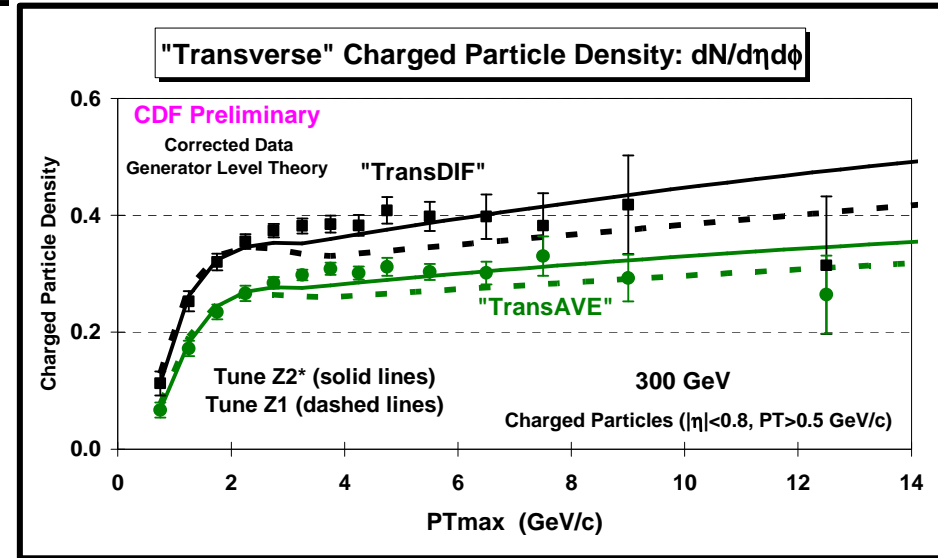


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “transAVE” and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.



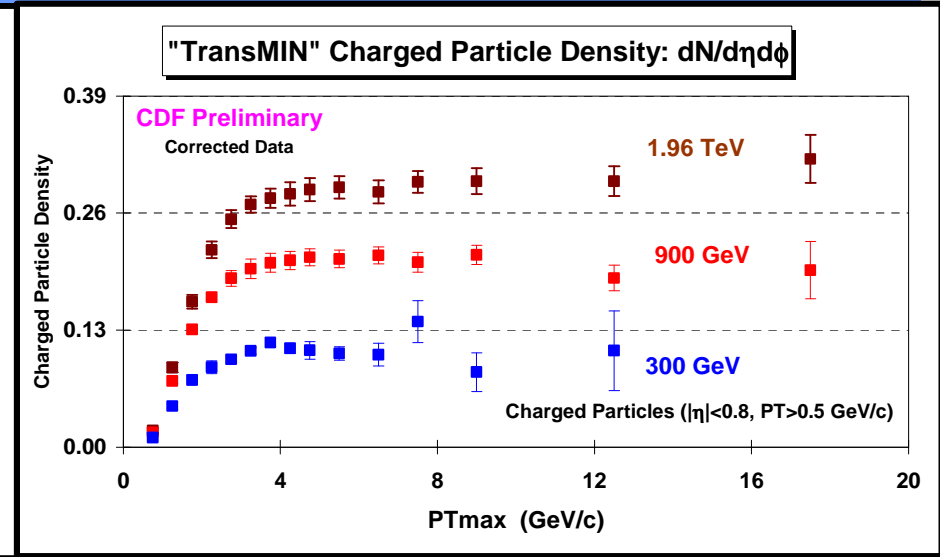
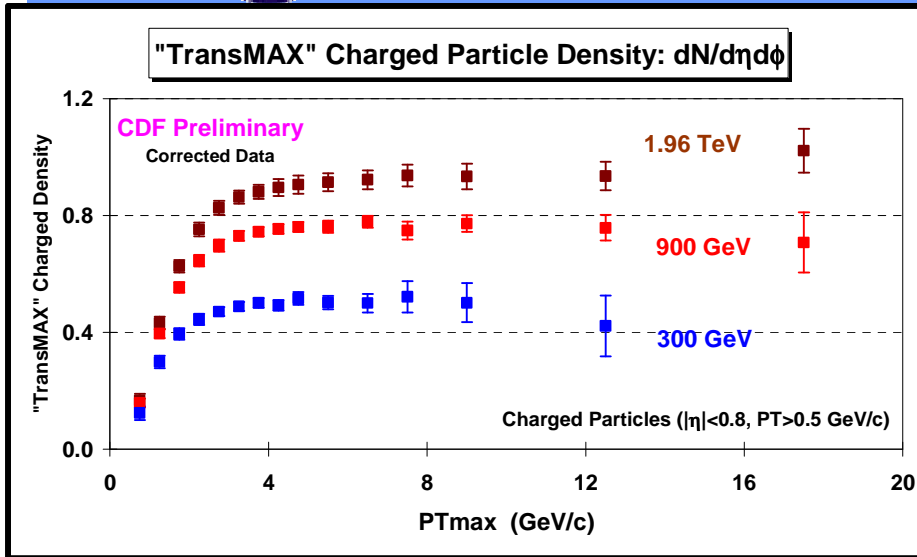


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transAVE” and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

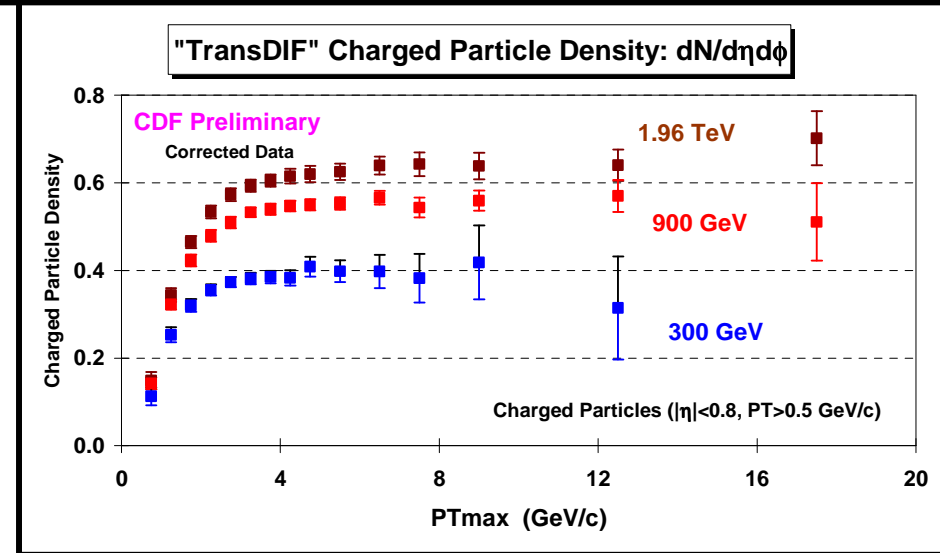


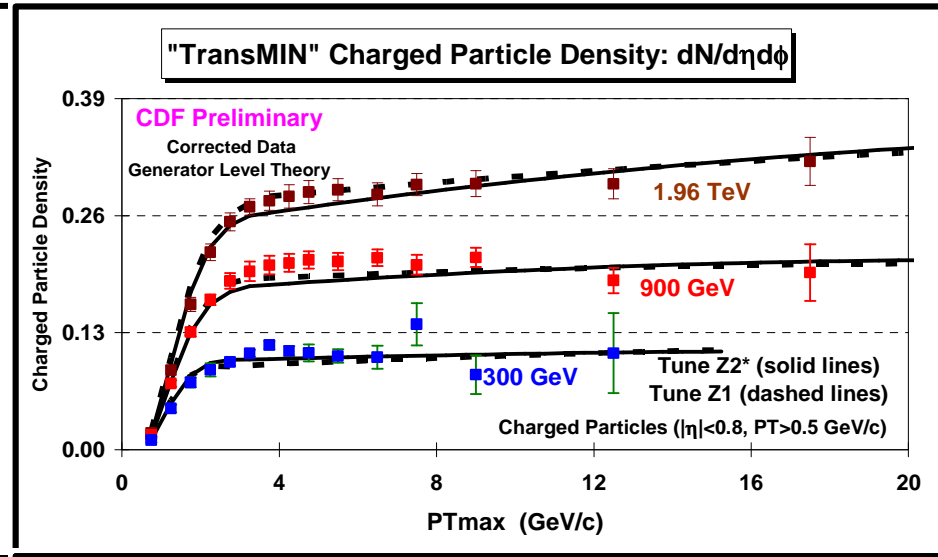
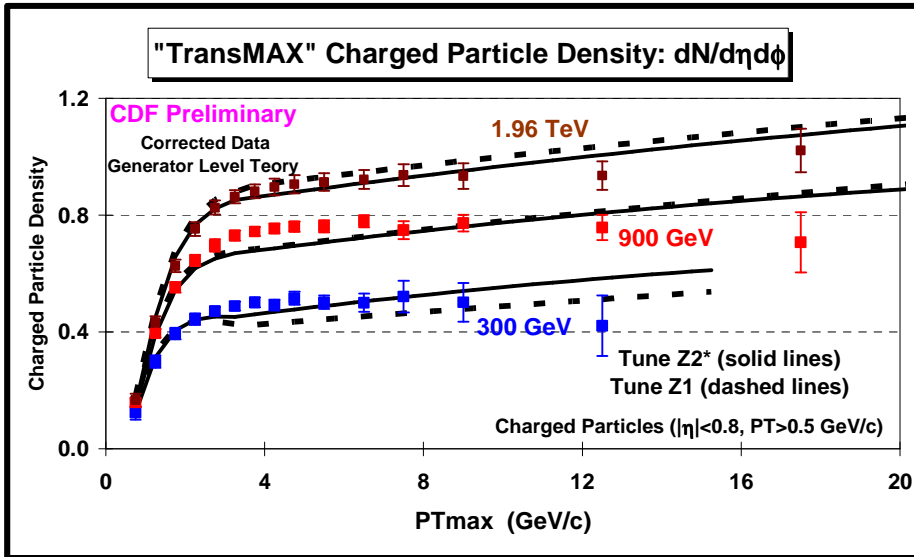


“transMAX/MIN” NchgDen



➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transMAX”, “transMIN”, and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

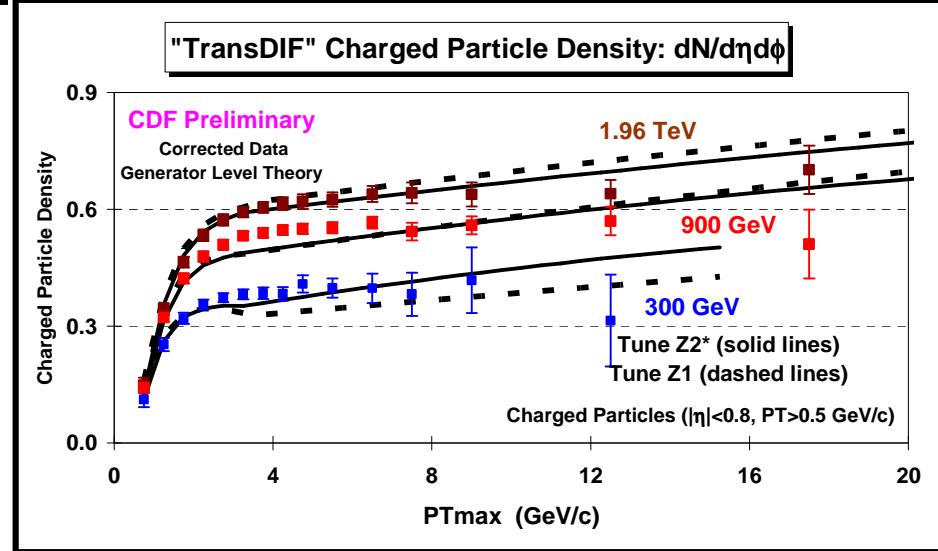




➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “transMAX”, “transMIN”, and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

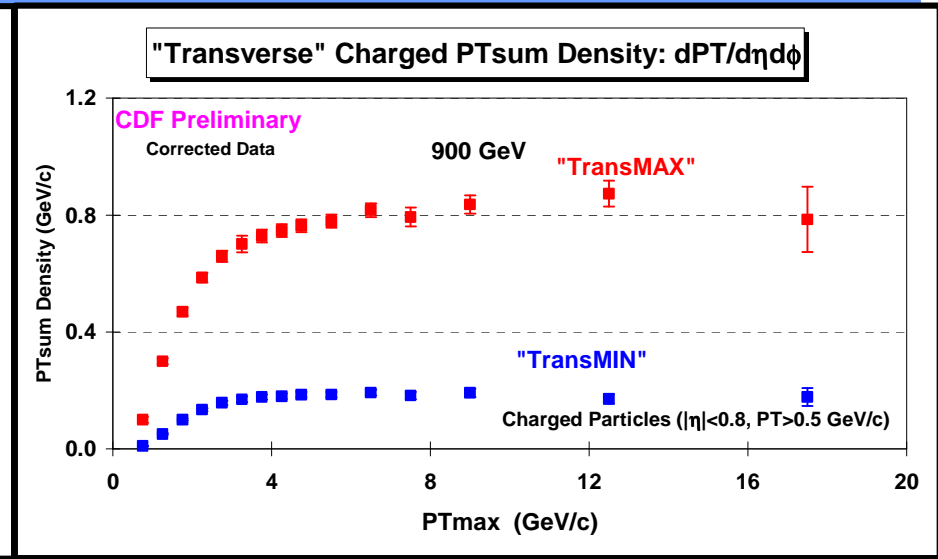
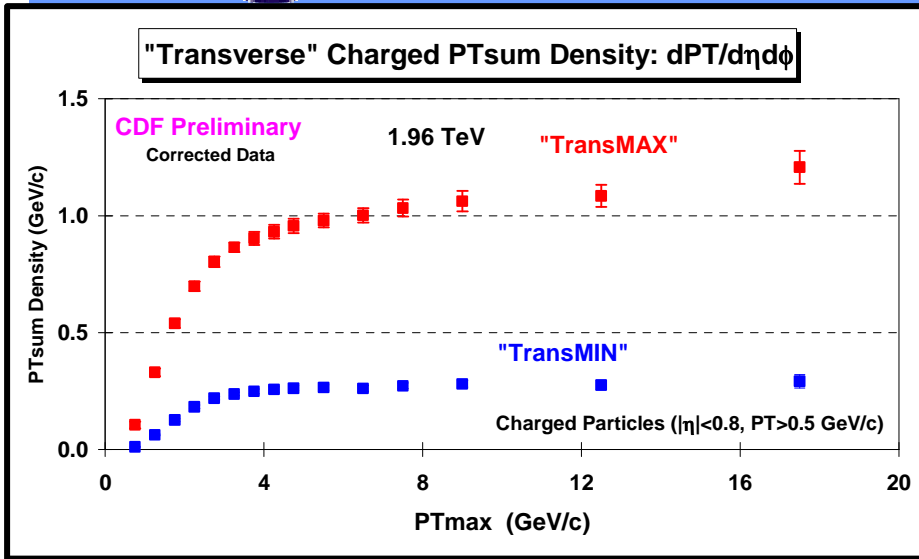
The data are compared with PYTHIA 6.4

Tune Z1 and Tune Z2*.

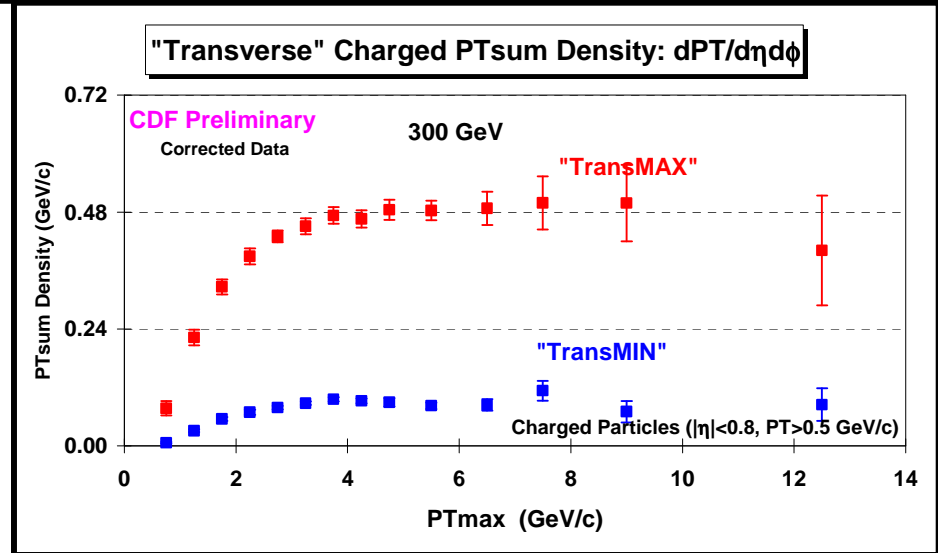




“transMAX/MIN” PTsumDen

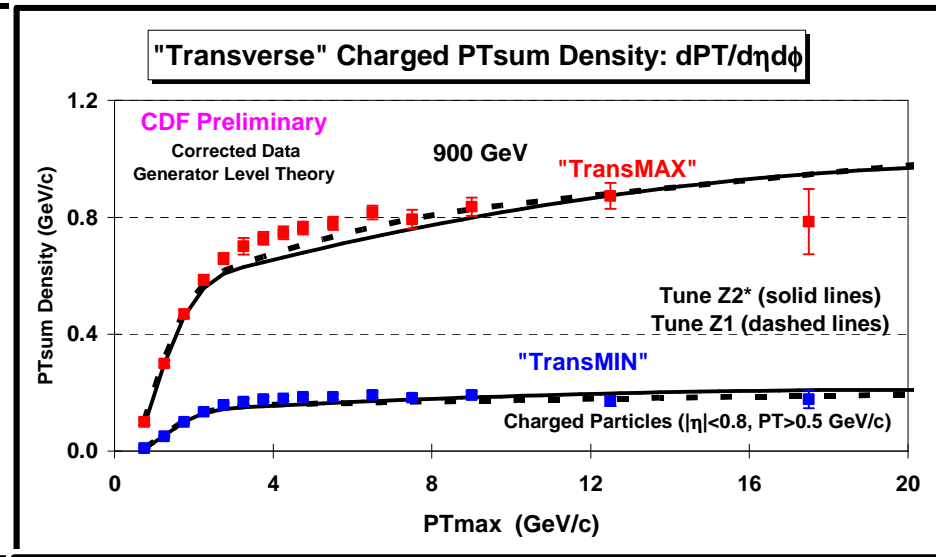
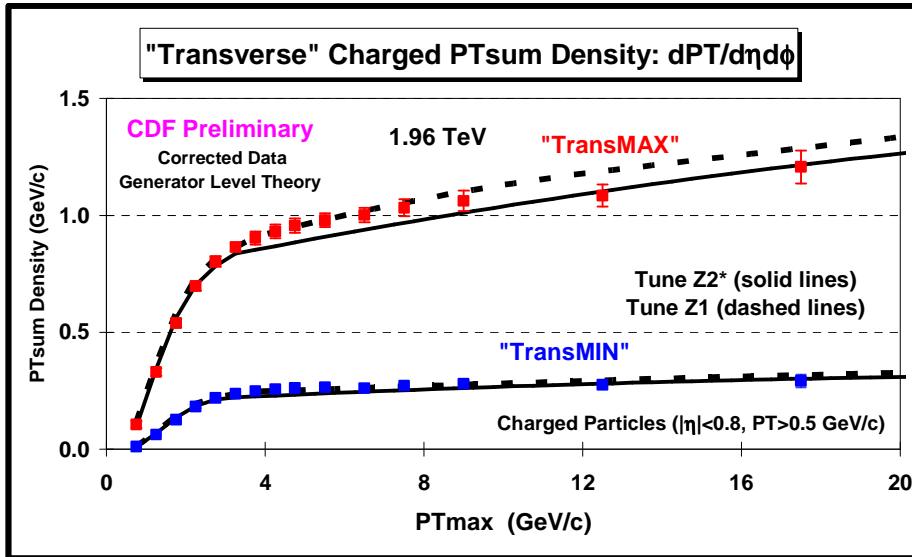
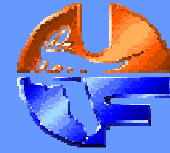


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the “transMAX” and “transMIN” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**





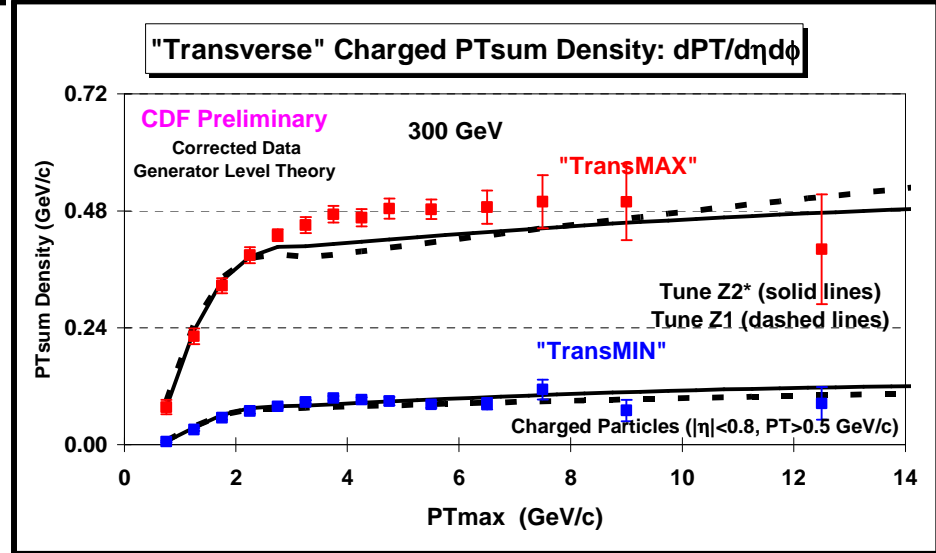
“transMAX/MIN” PTsumDen



→ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged PTsum density in the “transMAX” and “transMIN” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

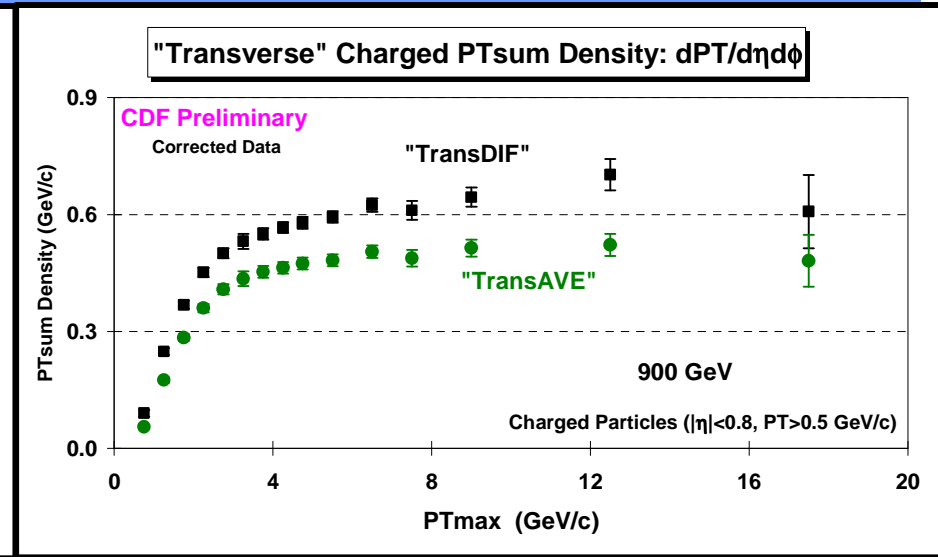
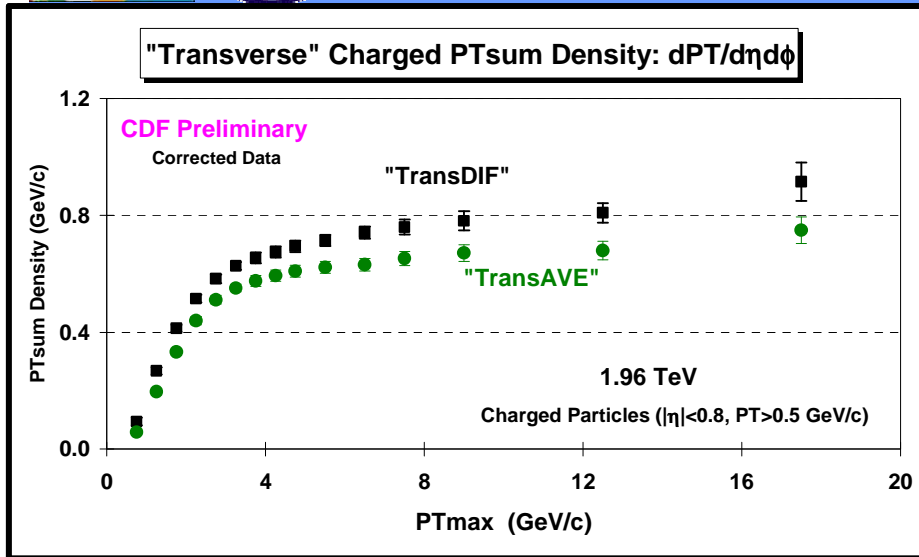
The data are compared with PYTHIA 6.4

Tune Z1 and Tune Z2*.

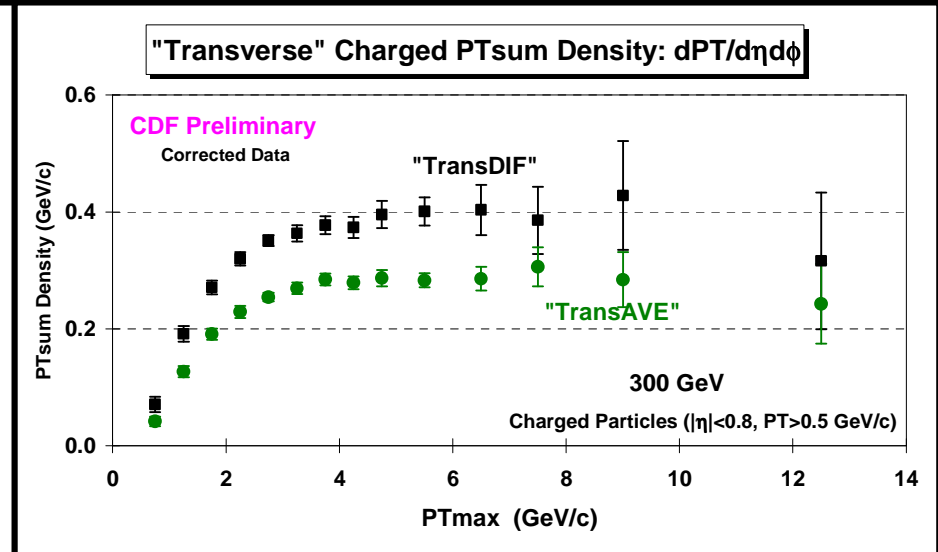


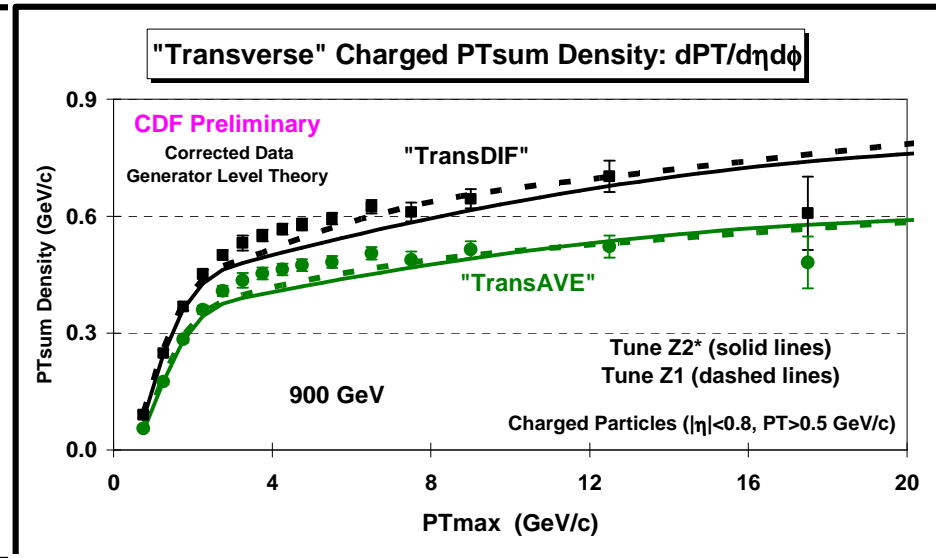
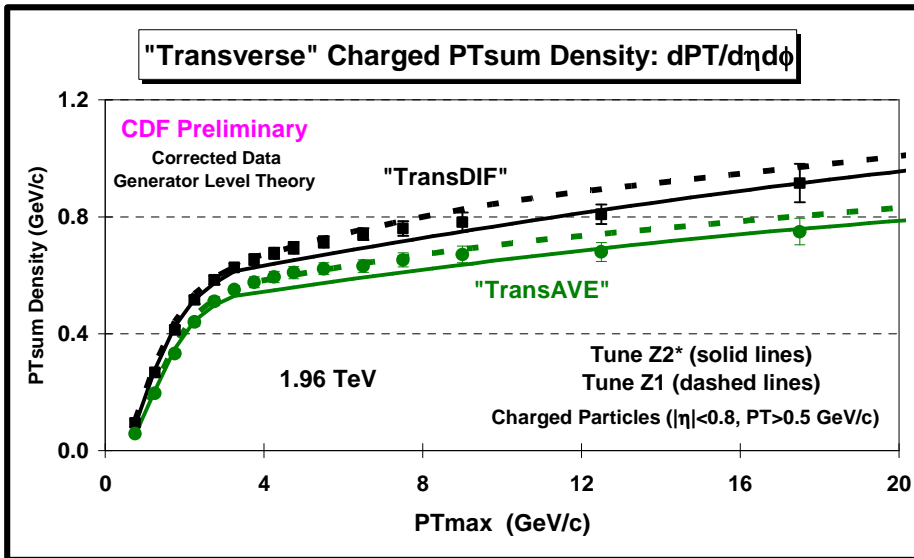


“transDIF/A VE” PTsumDen



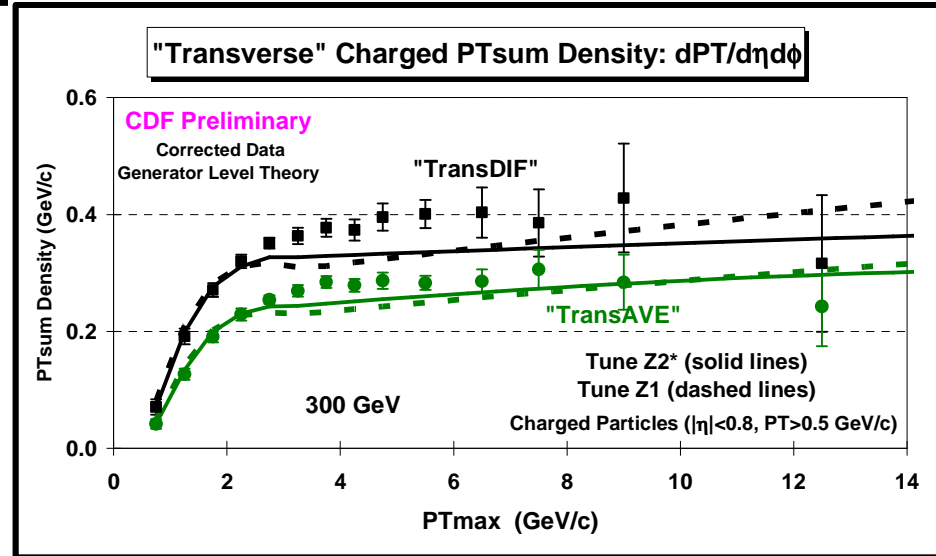
➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the “transAVE” and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**





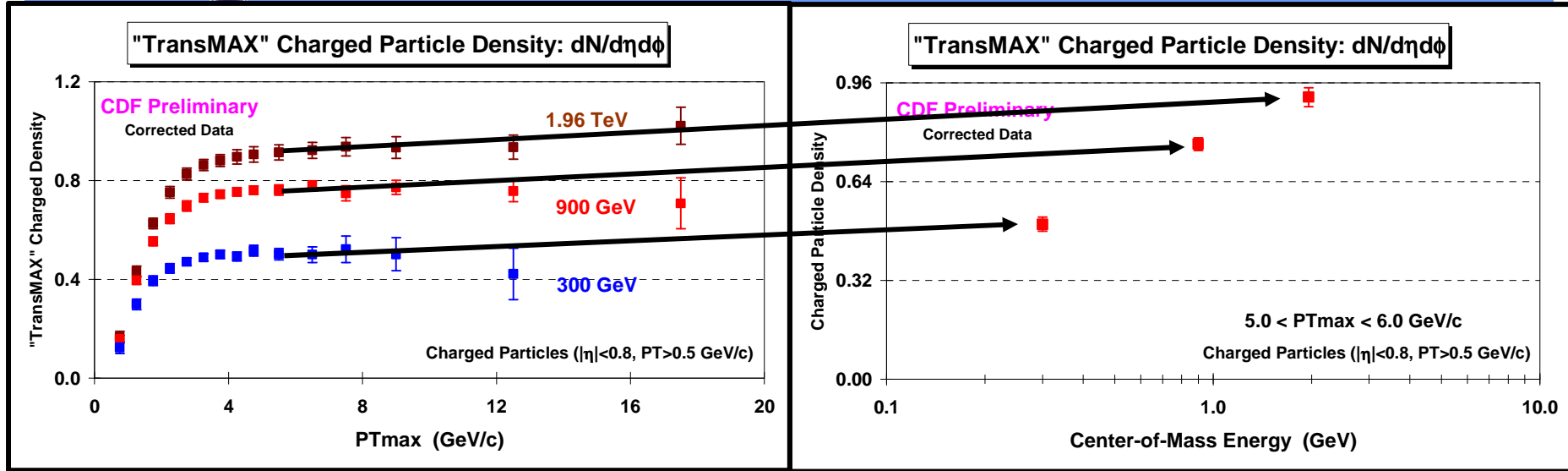
➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged PTsum density in the “transAVE” and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.





“transMAX” NchgDen vs E_{cm}

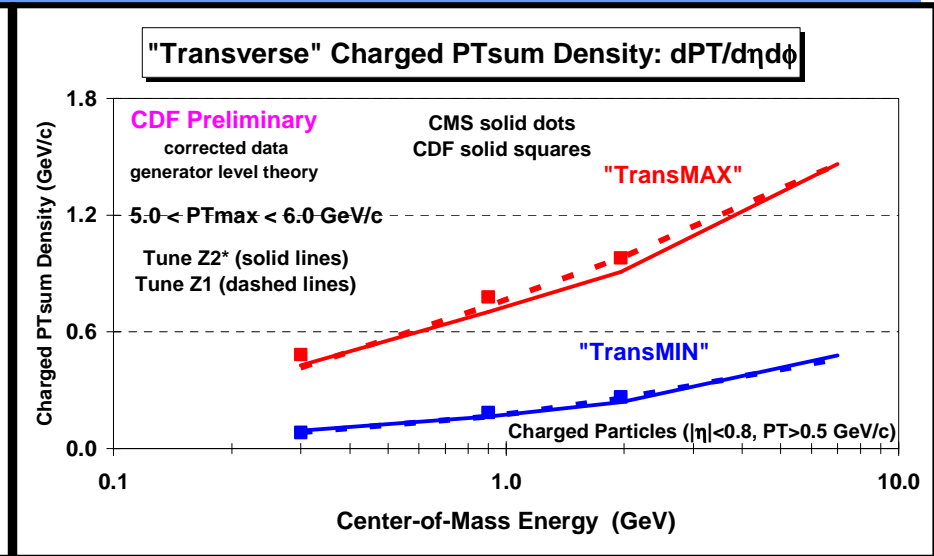
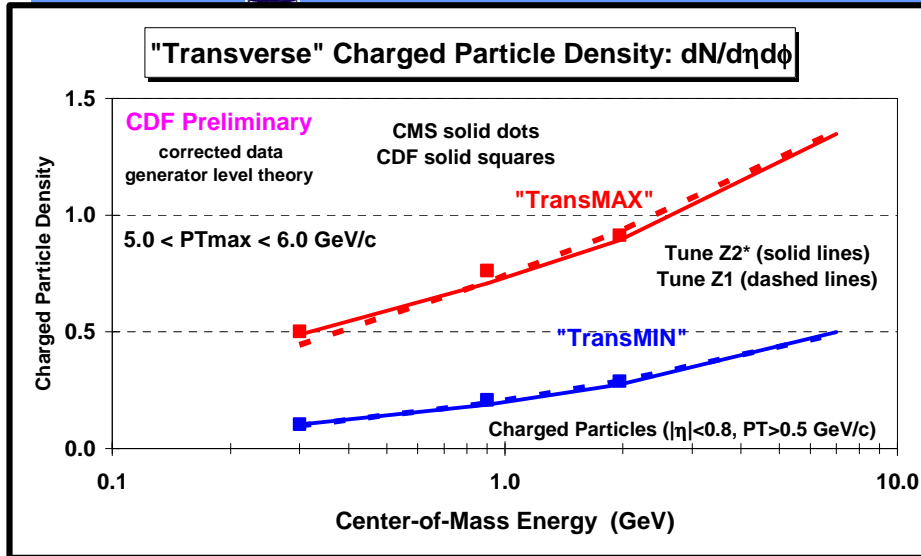
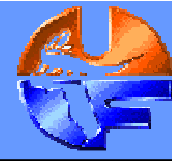


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “transMAX” region as defined by the leading charged particle (PT_{max}) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

➔ **Corrected CDF data** on the charged particle density in the “transMAX” region as defined by the leading charged particle (PT_{max}) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PT_{max} < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).



“TransMAX/MIN” vs E_{cm}

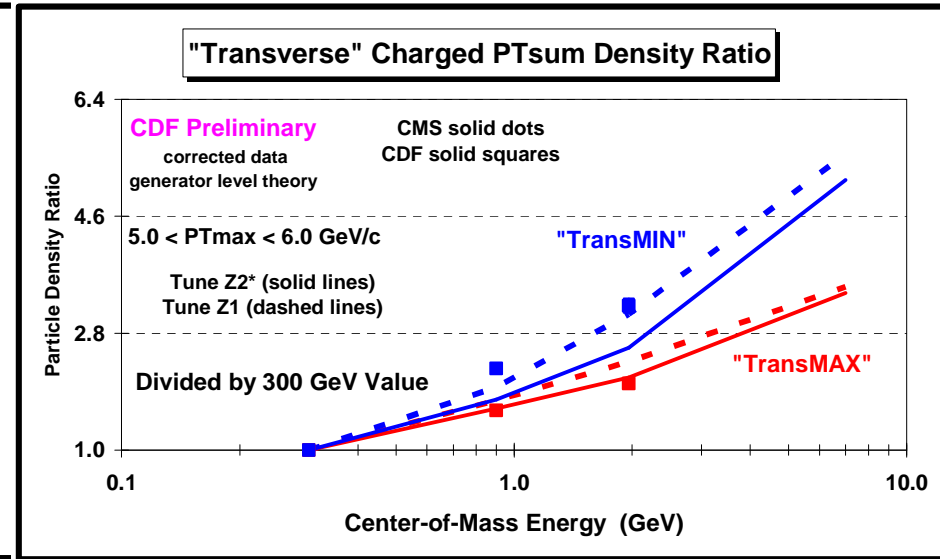
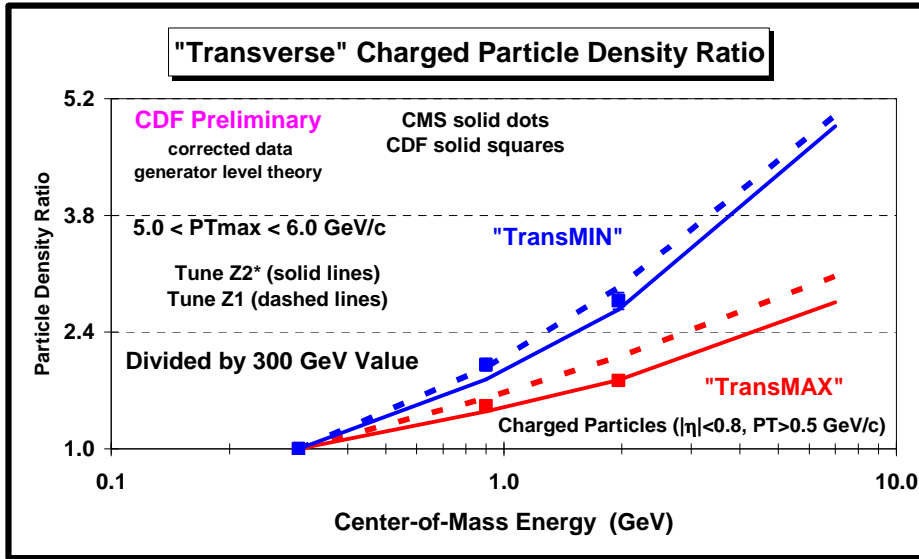
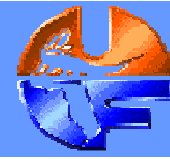


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transMAX”, and the “transMIN”, regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.**

➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the “transMAX”, and the “transMIN”, regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.**



“TransMAX/MIN” vs E_{cm}



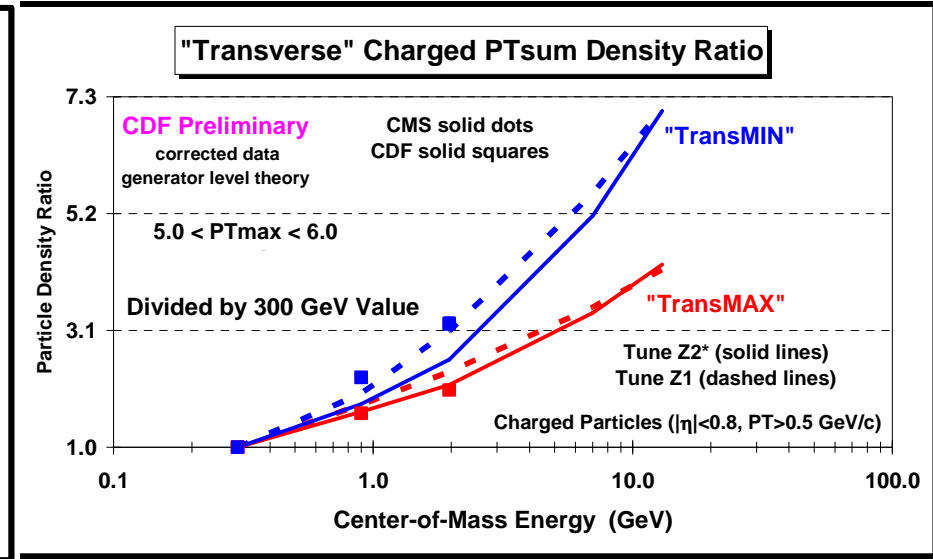
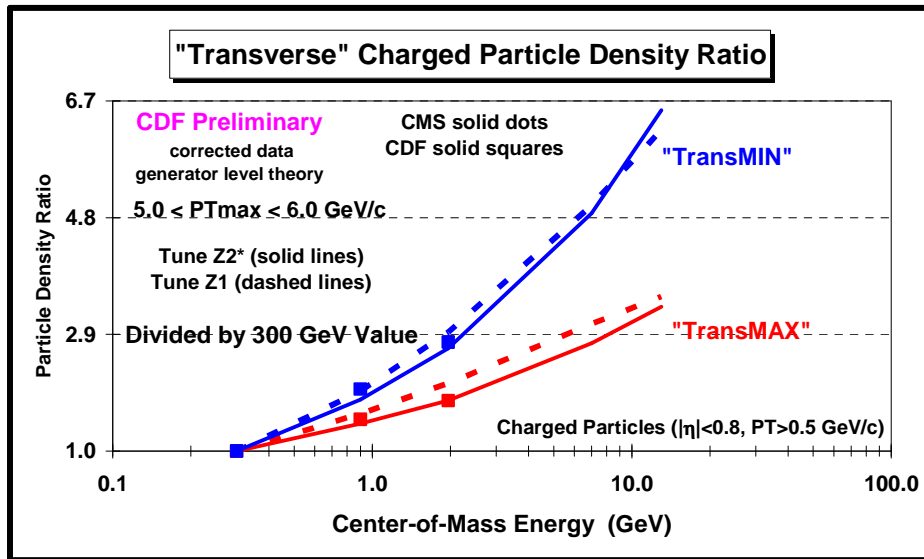
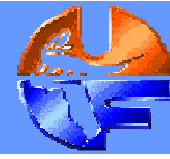
➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transMAX”, and the “transMIN”, regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.**

➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the “transMAX”, and the “transMIN”, regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.**

The data are “normalized” by dividing by the corresponding value at 300 GeV.



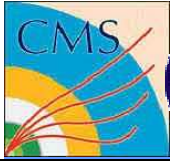
“TransMAX/MIN” vs E_{cm}



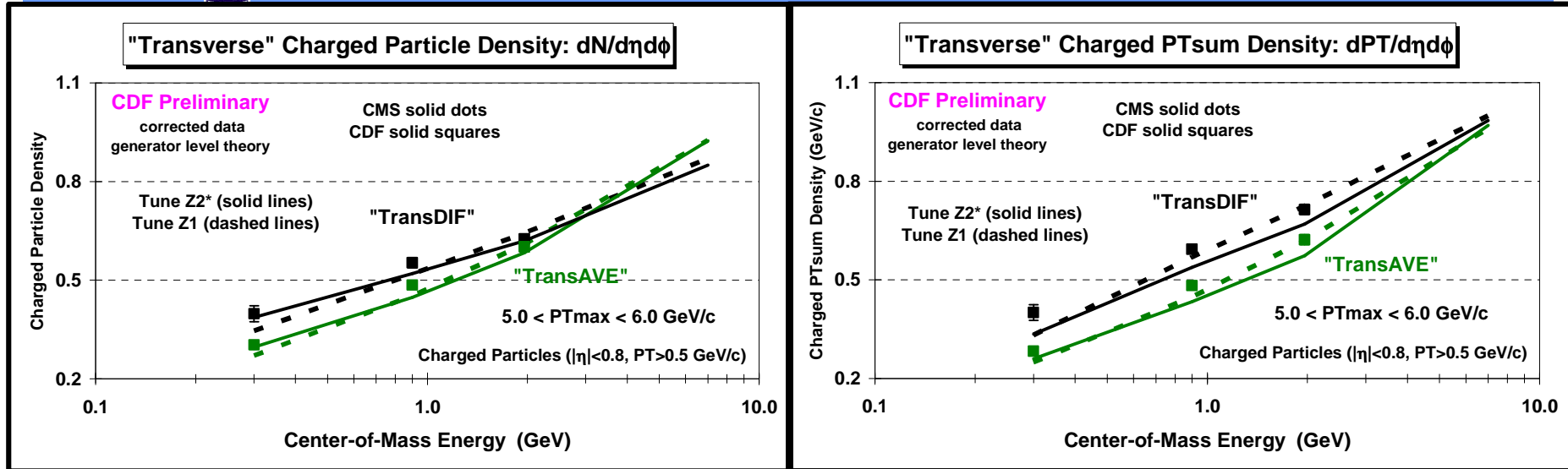
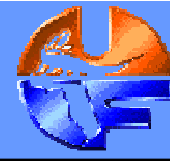
➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transMAX”, and the “transMIN”, regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.**

➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the “transMAX”, and the “transMIN”, regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.**

The data are “normalized” by dividing by the corresponding value at 300 GeV.



“TransDIF/A VE” vs E_{cm}

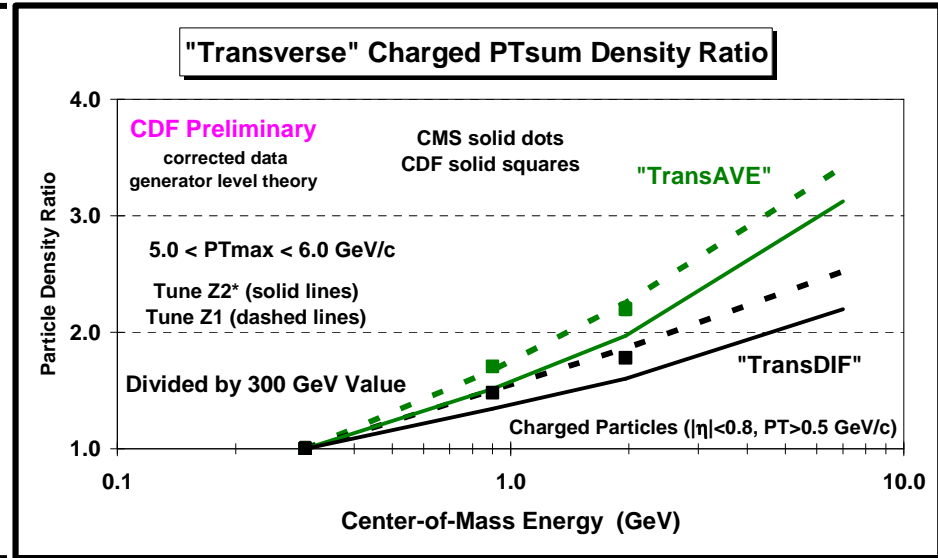
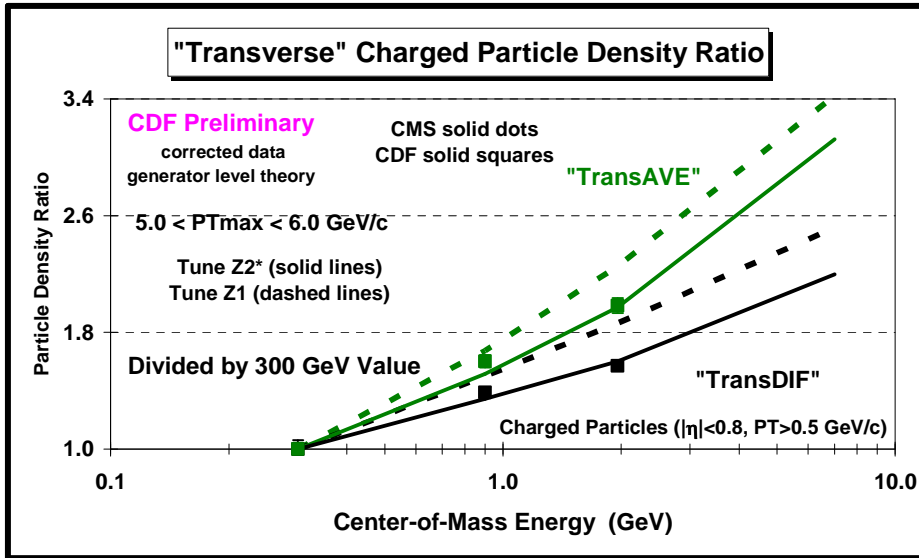


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “**transAVE**”, and the “**transDIF**”, regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PT_{max} < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.

➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged PTsum density in the “**transAVE**”, and the “**transDIF**”, regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PT_{max} < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.



“TransDIF/A VE” vs E_{cm}

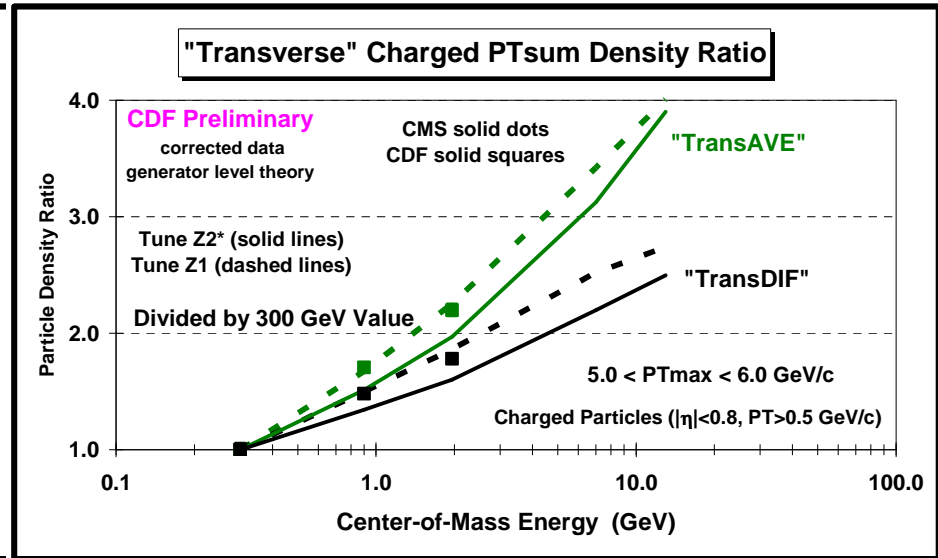
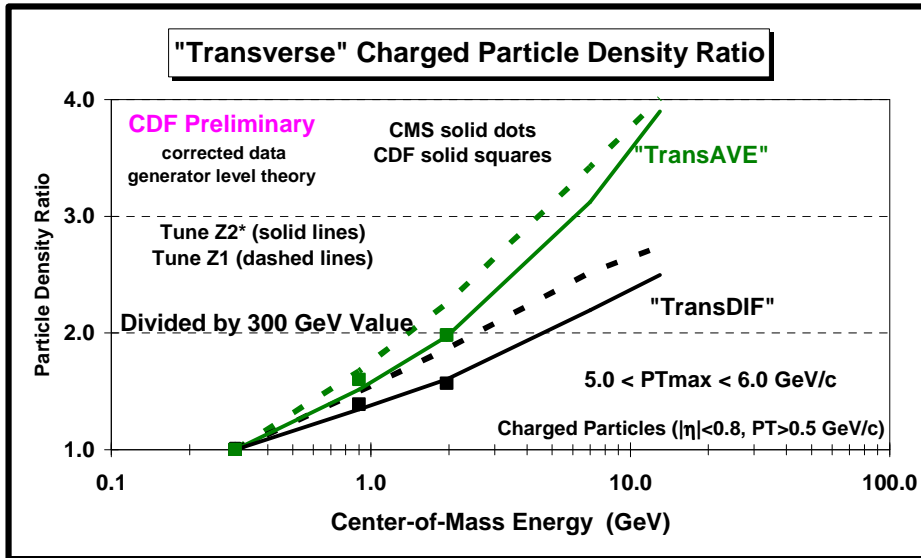


➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “**transAVE**”, and the “**transDIF**”, regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.

➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged PTsum density in the “**transAVE**”, and the “**transDIF**”, regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.

The data are “normalized” by dividing by the corresponding value at 300 GeV.

“TransDIF/A VE” vs E_{cm}



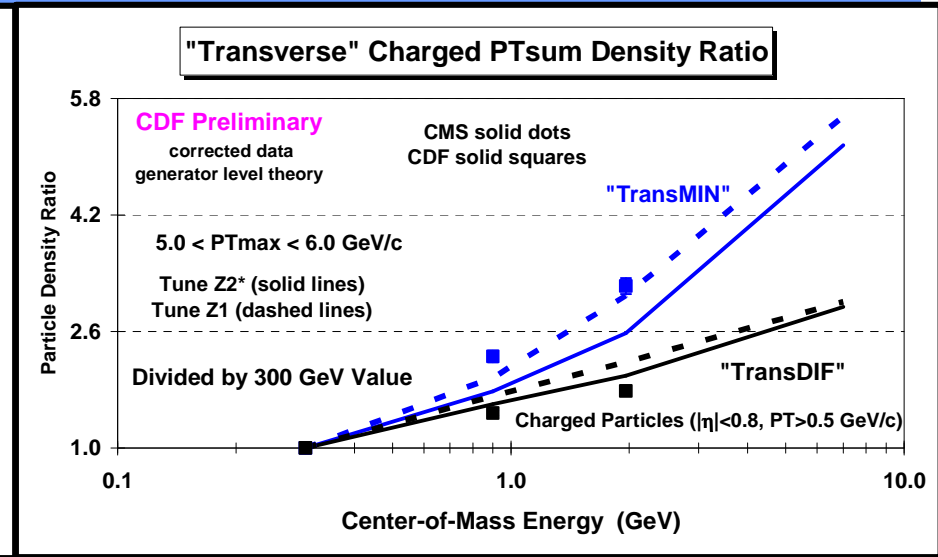
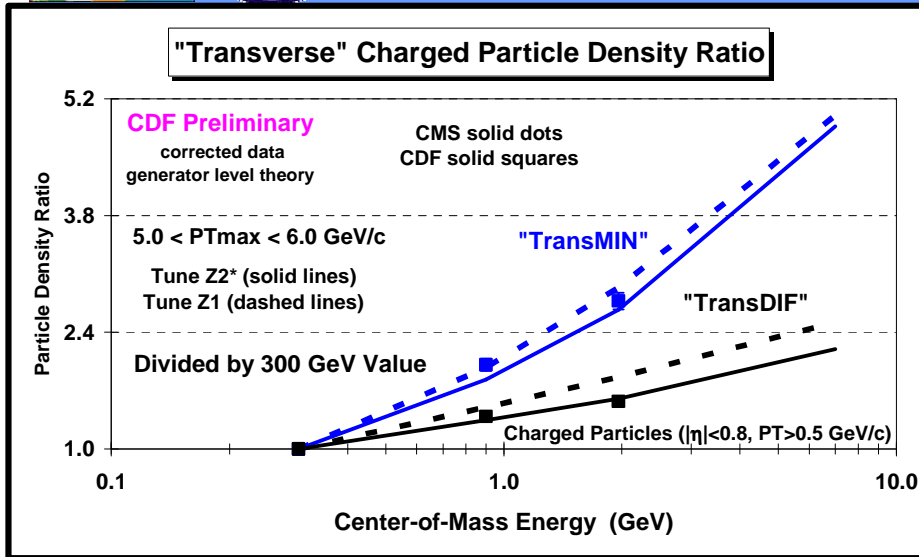
➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “**transAVE**”, and the “**transDIF**”, regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.

➔ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged PTsum density in the “**transAVE**”, and the “**transDIF**”, regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.

The data are “normalized” by dividing by the corresponding value at 300 GeV.



“TransMIN/DIF” vs E_{cm}

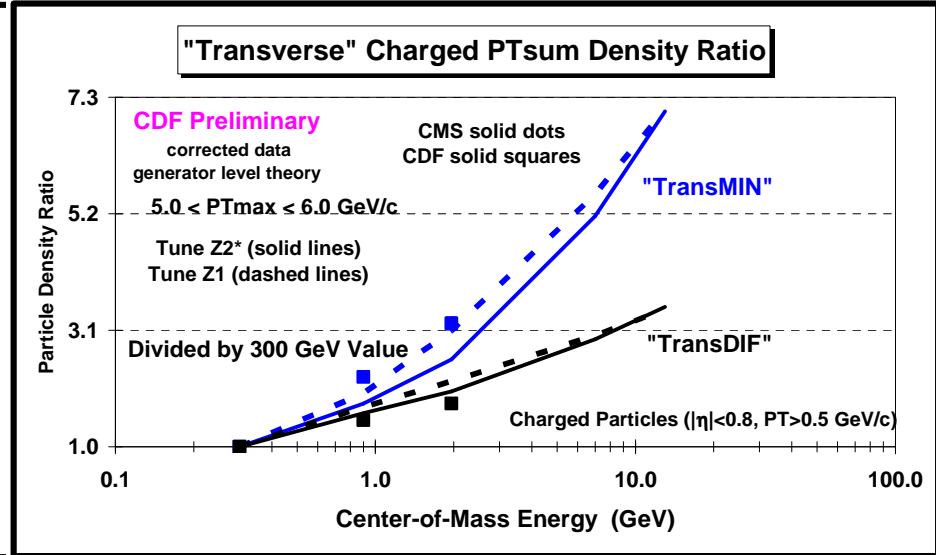
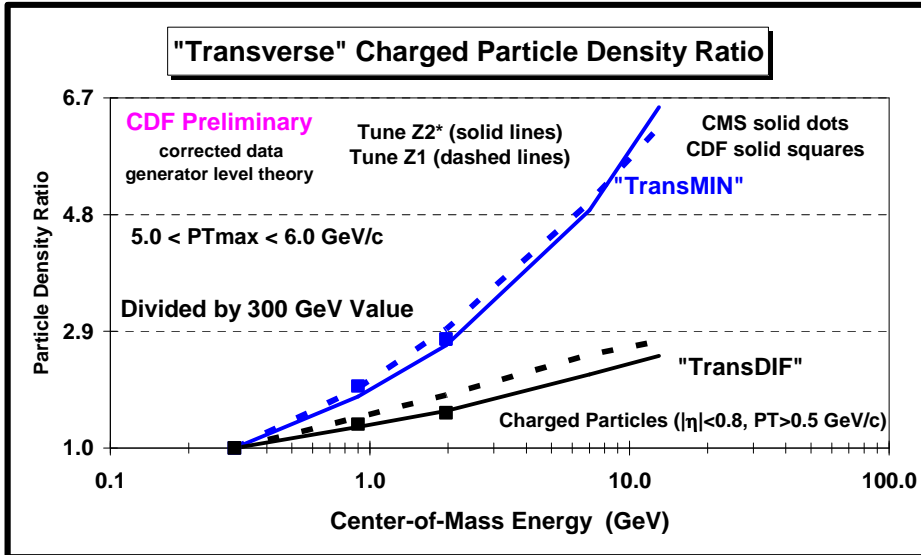


→ **Ratio of CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged particle density in the “transMIN”, and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.**

→ **Ratio of CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged PTsum density in the “transMIN”, and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.**

The data are “normalized” by dividing by the corresponding value at 300 GeV.

“TransMIN/DIF” vs E_{cm}



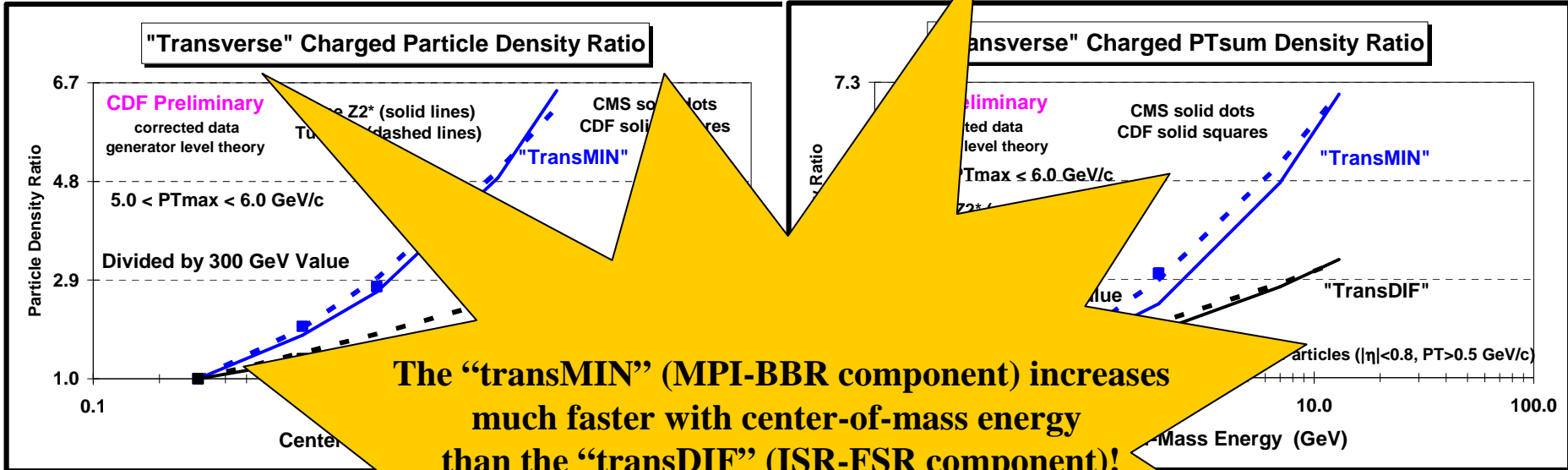
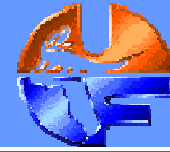
➔ **Ratio of CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged particle density in the “transMIN”, and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PT_{max} < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.**

➔ **Ratio of CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged PTsum density in the “transMIN”, and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PT_{max} < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.**

The data are “normalized” by dividing by the corresponding value at 300 GeV.



“TransMIN/DIF” vs E_{cm}



The “transMIN” (MPI-BBR component) increases much faster with center-of-mass energy than the “transDIF” (ISR-FSR component)!

Duh!!

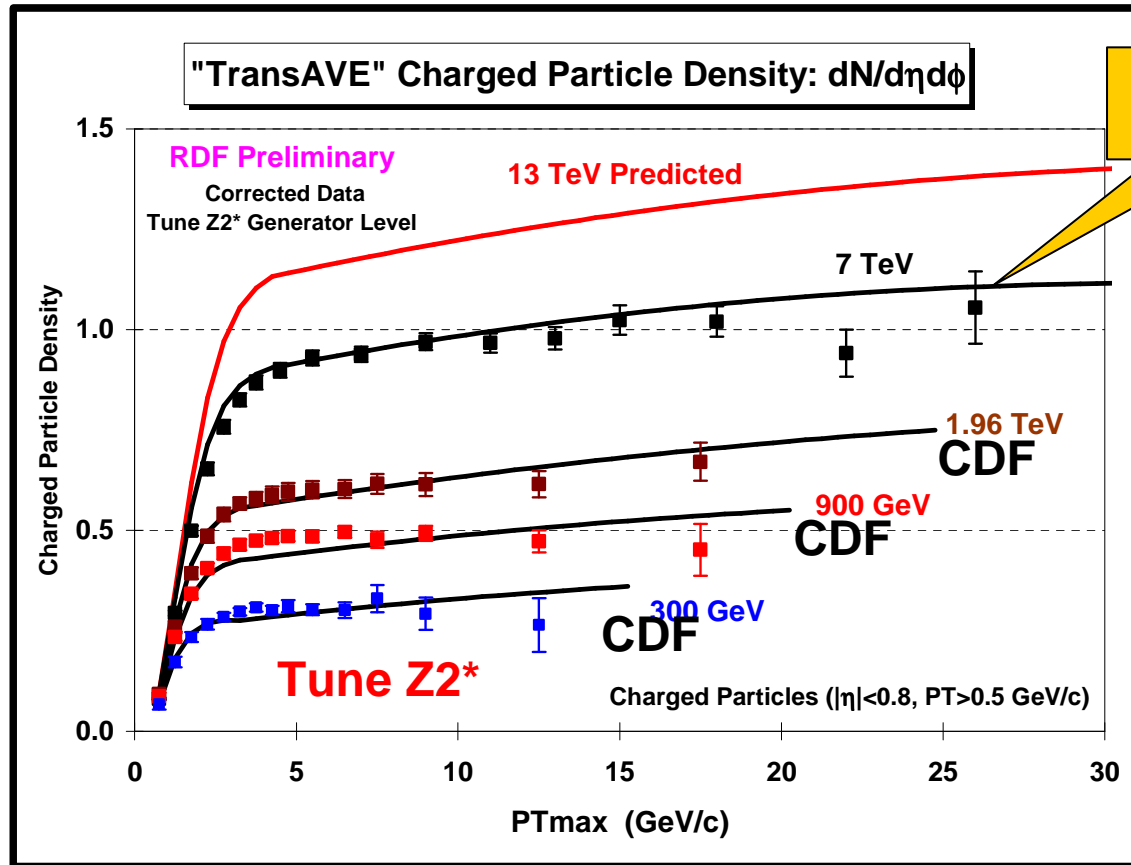
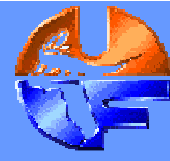
→ **Ratio of CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the x** charged particle and “transDIF” as use leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.

→ **Ratio of CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the x** charged particle density in the “transMIN”, and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 **Tune Z1** and **Tune Z2***.

The data are “normalized” by dividing by the corresponding value at 300 GeV.



“Tevatron” to the LHC

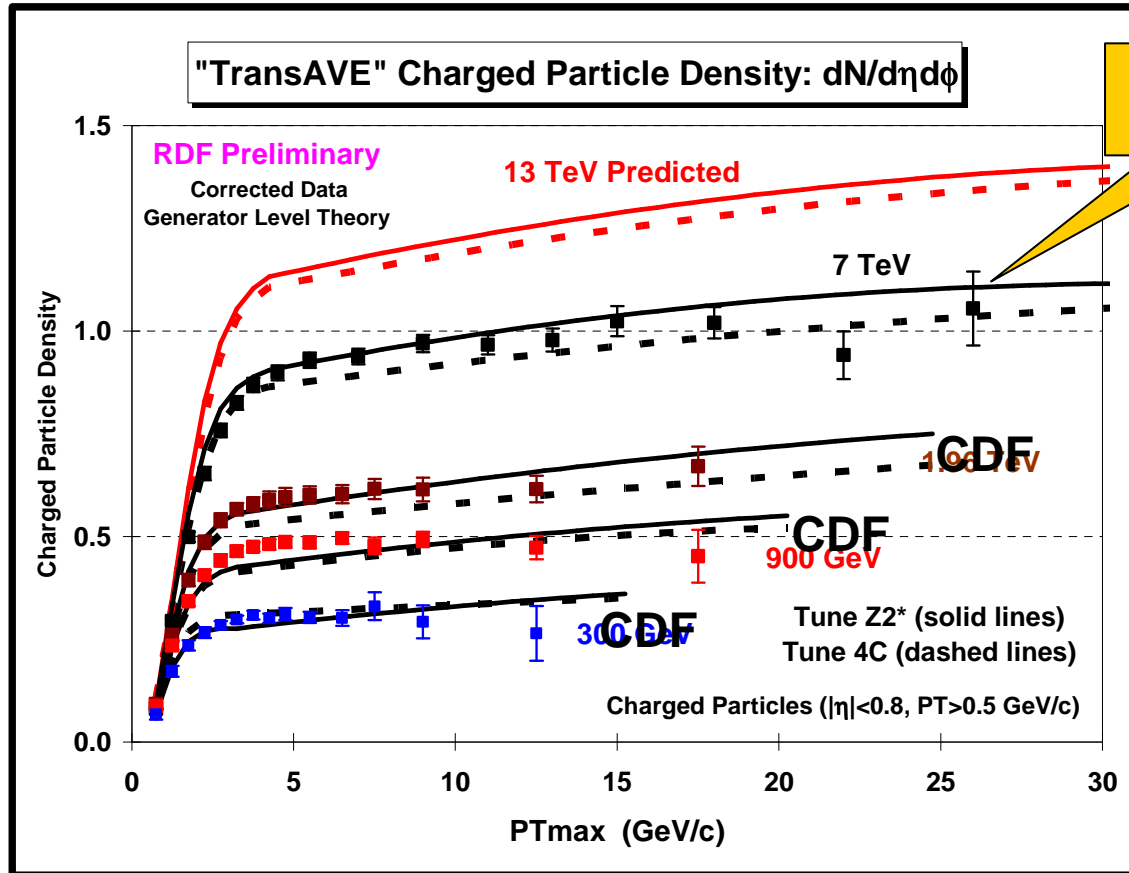
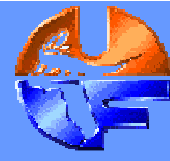


CMS

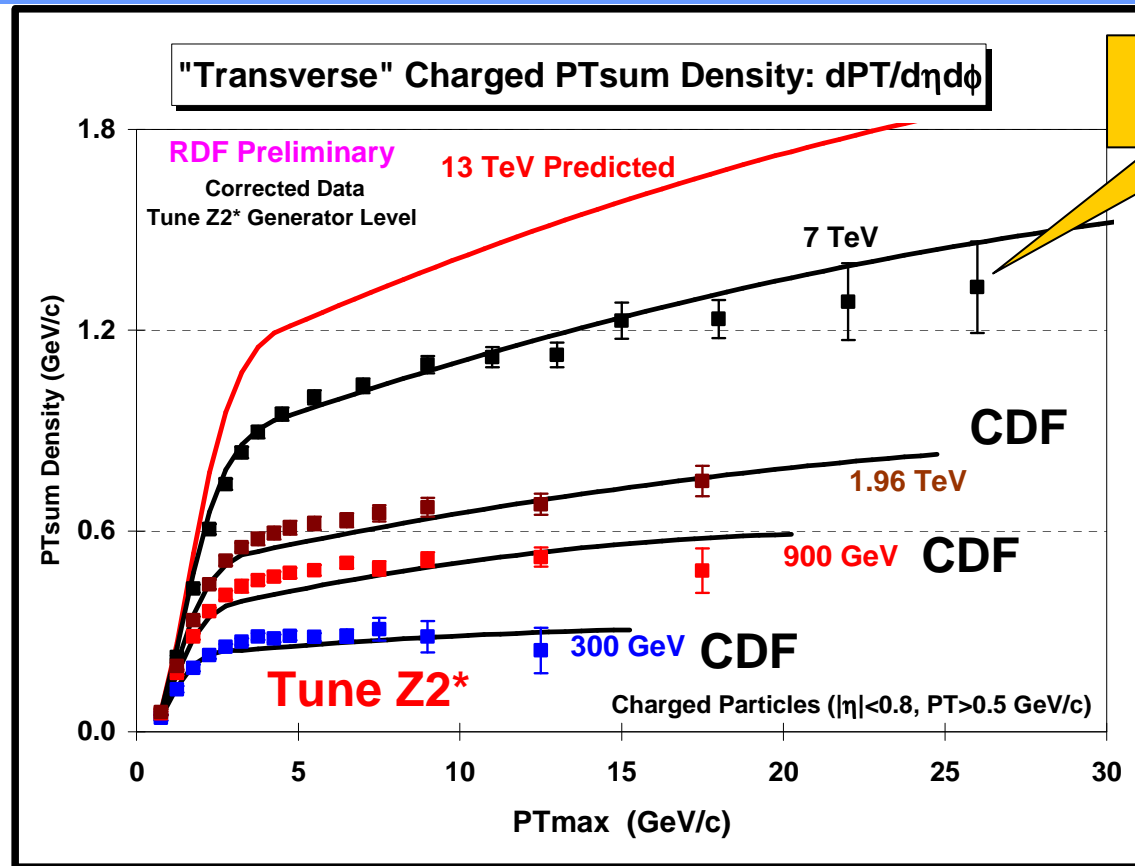
PYTHIA 8 Tune 4C (dashed lines) - Corke & Sjöstrand



“Tevatron” to the LHC

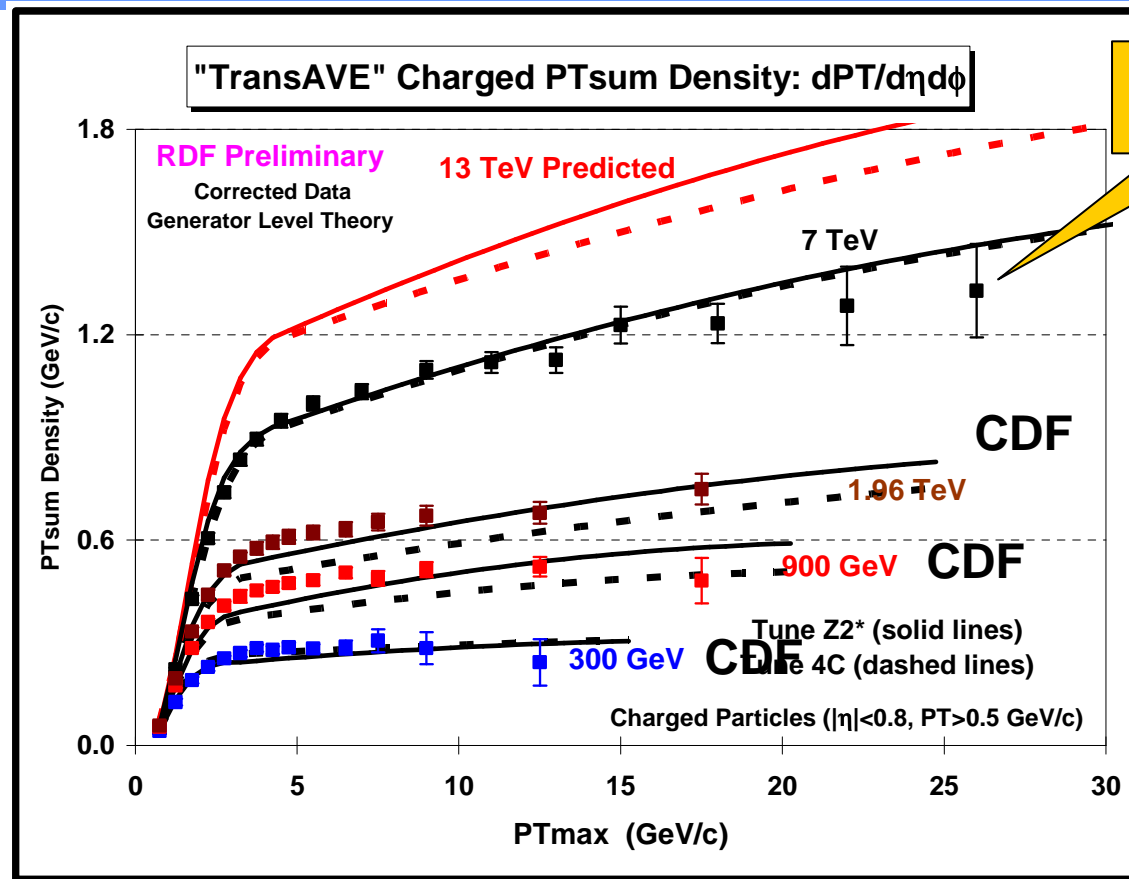
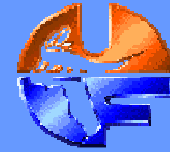


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“Tevatron” to the LHC



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Summary & Conclusions



- ➔ The **“transverse”** density increases faster with center-of-mass energy than the overall density ($N_{chg} \geq 1$)! However, the **“transverse” = “transAVE”** region is not a true measure of the energy dependence of MPI since it receives large contributions from ISR and FSR.
- ➔ The **“transMIN”** (MPI-BBR component) increases much faster with center-of-mass energy than the **“transDIF”** (ISR-FSR component)! Previously we only knew the energy dependence of **“transAVE”**.

We now have a lot of MB & UE data at 300 GeV, 900 GeV, 1.96 TeV, and 7 TeV!
We can study the energy dependence more precisely than ever before!

- ➔ Both PYTHIA 6.4 **Tune Z1** (CTEQ5L) and PYTHIA 6.4 **Tune Z2*** (CTEQ6L) do a fairly good job (although not perfect) in describing the energy dependence of the UE!

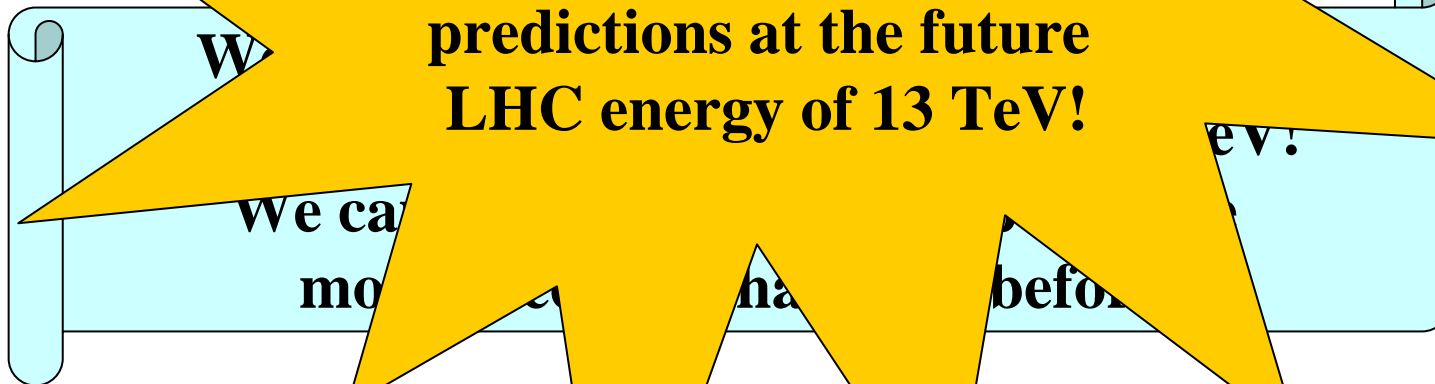


Summary & Conclusions



→ The “**transverse**” density increases faster with center-of-mass energy than the total density (Nch). However, the “**transverse**” = “**transA VE**” is not a simple function of energy, due to the dependence of MPI since it rises with energy.

→ The “**transMIN**” What we are learning should allow for a deeper understanding of MPI which will result in more precise predictions at the future LHC energy of 13 TeV!



→ Both PYTHIA 6.4 **Tune Z1** (CTEQ5L) and PYTHIA 6.4 **Tune Z2*** (CTEQ6L) go a fairly good job (although not perfect) in describing the energy dependence of the UE.